Appendix F: Modeling Reports

F.1 Report: *Industrial Area Post-Closure (2007) Integrated Surface-Subsurface Hydrologic and Hydraulic Flow System Assessment and Model Update, Rocky Flats Site*

January 28, 2008

MEMORANDUM

TO: John Boylan, S.M. Stoller

FROM: Bob Prucha, Integrated Hydro Systems, LLC

SUBJECT: Industrial Area Post-Closure (2007) Integrated Surface-Subsurface Hydrologic and Hydraulic Flow System Assessment and Model Update, Rocky Flats Site

This memorandum summarizes results of a post-closure integrated surface-subsurface hydrologic and hydraulic flow system assessment of the former Industrial Area (IA) at the Rocky Flats Site. Available post-closure data were evaluated and former integrated hydrologic flow models were updated. Model results were then assessed to see whether any significant changes from previous post-closure simulations have occurred.

This memorandum only summarizes updates to the IA VOC flow model that reflect post-closure configuration modifications to the system. Changes to model input for two other models are described in more detail in two concurrent, but separate, memoranda.

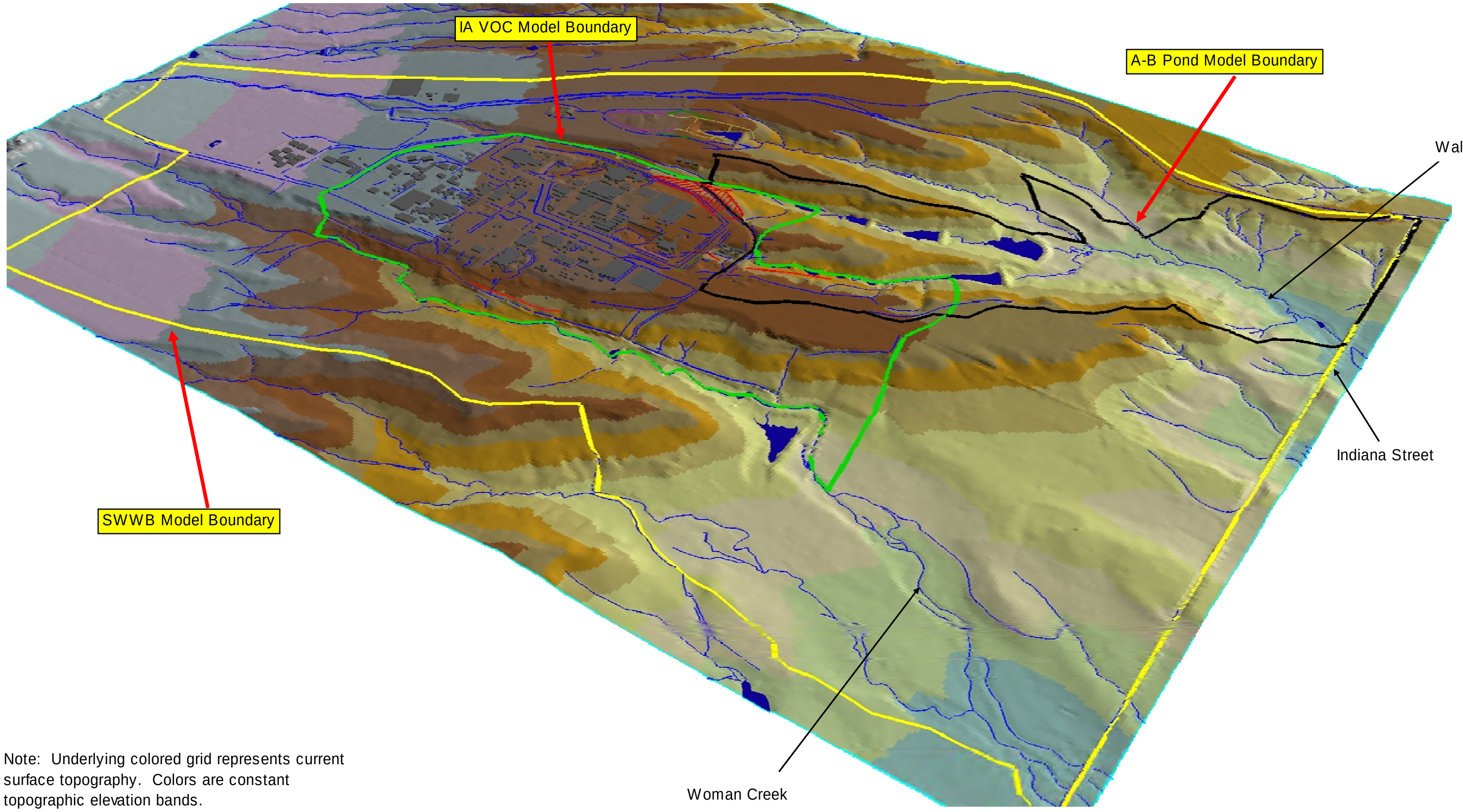
1.0 Scope of Work

The contract that Integrated Hydro Systems (IHS) received from S.M. Stoller (Stoller) in August-September 2005 defined most of the anticipated work in three general categories as follows:

1) Update existing computer models as new data become available;
2) Report results of site modeling, including in the Annual Site Surveillance and Maintenance Report; and
3) Develop new computer models as required.

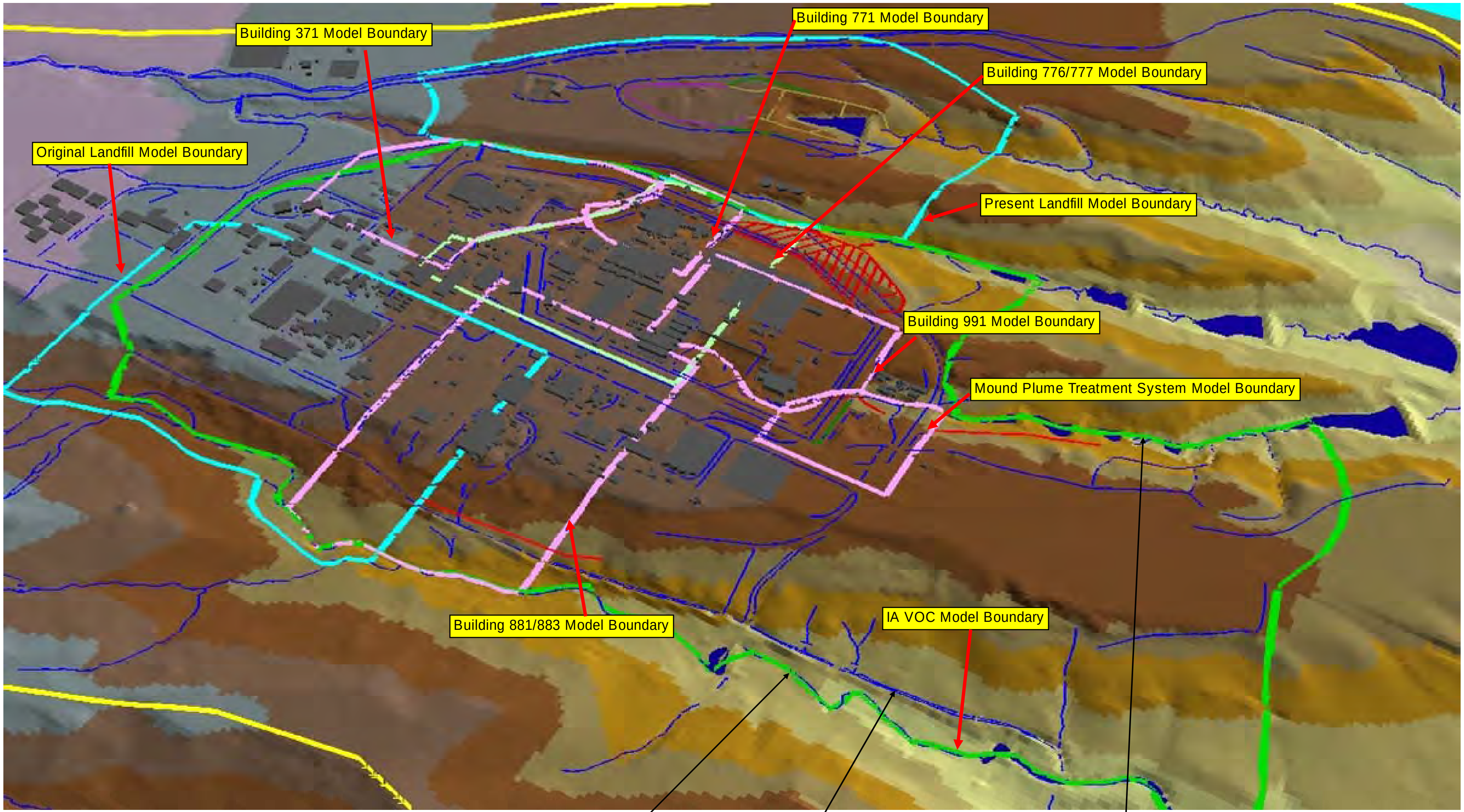
Details associated with each of these tasks are described below:

1) Integrated surface/subsurface flow models developed in support of Rocky Flats Environmental Technology Site (RFETS) closure were last summarized in the report "Summary of Hydrologic Flow and Fate and Transport Modeling Conducted at the Rocky Flats Environmental Technology Site," dated October 2005. Computer models that could be updated using recent post-closure monitoring data include the following:
    - Site-Wide Water Balance (SWWB) model that covers the entire former RFETS property (Figure 1);
    - IA Volatile Organic Compound (VOC) higher-resolution SWWB model, which was the basis for VOC fate/transport modeling (Figures 1 and 2);
    - Original Landfill (OLF) model and Present Landfill (PLF) model (Figure 2);
    - Local, high-resolution integrated flow models for key former building areas (881/883, 771, 444-same as OLF model, 371, and 991) (Figure 2);
    - Local, high-resolution Mound Site Plume Treatment System (MSPTS) integrated flow model (Figure 2); and
    - VOC transport models for each plume area (Figure 3).



Note: Underlying colored grid represents current surface topography. Colors are constant topographic elevation bands.

Figure 1. SWWB and IA VOC model boundaries. Surface topography shown is from 2001.



Note: Underlying colored grid represents current surface topography. Colors are constant topographic elevation bands.

Figure 2. Local integrated flow model boundaries, including the IA VOC model boundary. Topography shown is from 2001.

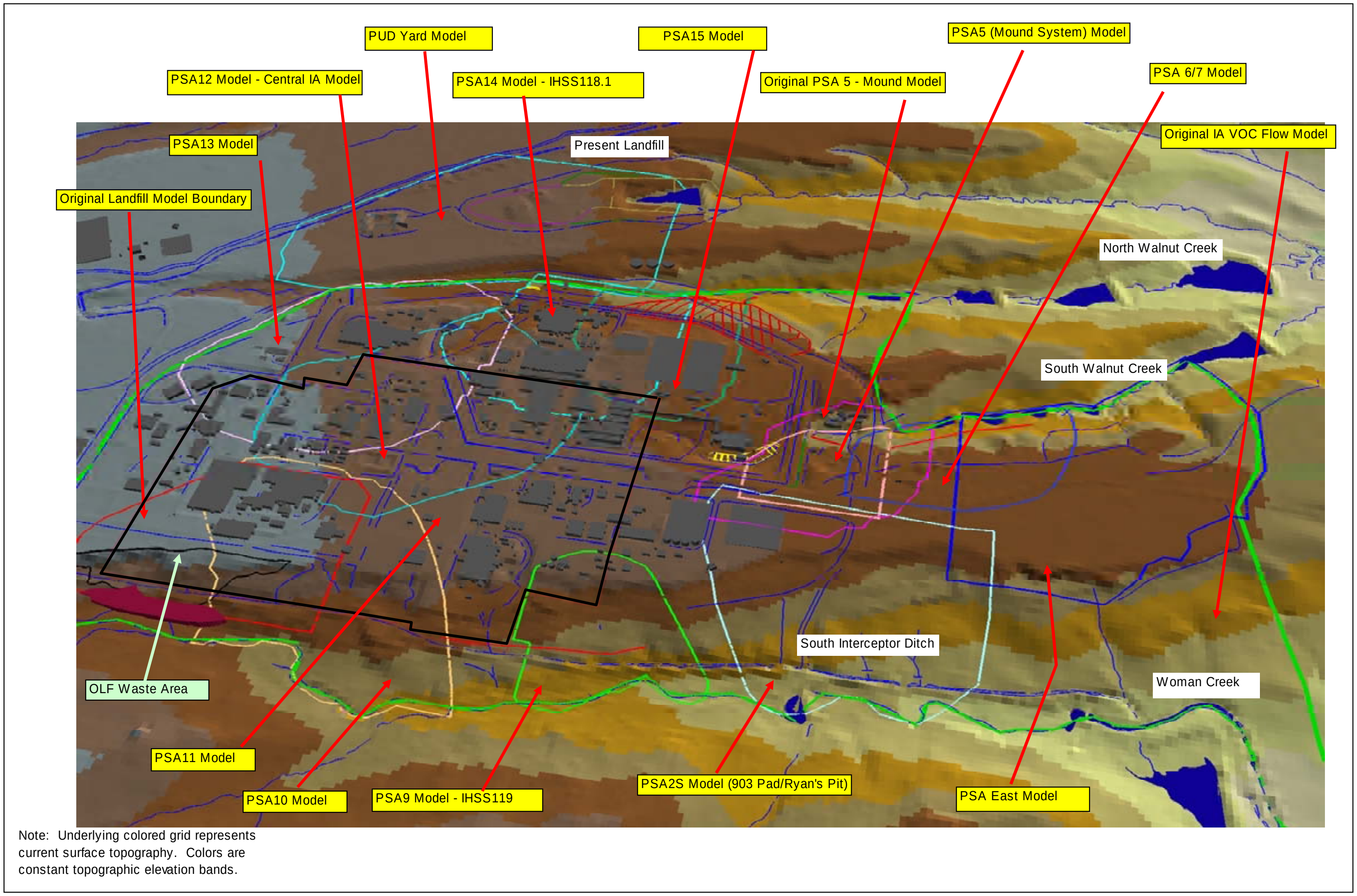


Figure 3. Individual VOC plume model areas. Modeled with RT3D within the Ground Water Modeling System Interface. Topography shown is for 2001.

2) The reports on updated models will, at a minimum, consist of memorandums or letter reports. More detailed reporting in the form of white papers or bound volumes may be requested depending on the complexity of the updating effort. The reports will describe the actions involved in the updating, reference relevant previous reports, document the model inputs that have been updated, and provide the updated model results.

3) Two possible new models were suggested in late 2005: a localized, high-resolution VOC fate/transport model for the East Trenches Plume Treatment System, and another to simulate enhanced bioremediation at any of the Solar Ponds, East Trenches, or Mound Site Plume Treatment Systems. Based on April 2007 discussions with John Boylan (Stoller), these options do not seem warranted and thus will not be pursued further at this point.

The original 2005 scope did not define specific modeling objectives, basis, or approach for updating any of the models listed above. Stoller outlined several objectives and the basis for the model updates was subsequently defined as follows:

- Assess and report relative changes to the flow conditions and contaminant distributions between observed pre-closure (2000) and post-closure (2005/2006) based on available data.
- Assess and report differences between former post-closure simulated conditions and contaminant distributions (last updated October 2005) and available post-closure (post-December 2005) data.
- Update appropriate models given time/budget limitations, and specifically for areas where deviations between previous simulated post-closure and current observed post-closure conditions are significant. Focus on the U.S. Department of Energy (DOE)-retained land; it includes most of the former IA, the PLF, the OLF, and terminal ponds. Do not update models if they adequately simulate post-closure conditions, or they were not originally designed to simulate flow or transport realistically enough to capture post-closure conditions.
- Document the evaluation and model updates as follows:
    - Document reasons for any deviations, for example, because of different post-closure condition model input assumptions (such as climate or land configuration details), model limitations, model error, or interim conditions. Note that former post-closure simulations assumed things such as fully established mesic vegetation, which is not the case currently.
    - Document model updates including changes to flow and fate/transport conceptualizations, model input, and in model performance.
- Identify any data gaps in the current post-closure monitoring network.

2.0 Model Update and Evaluation Approach

The following approach to updating, simulating, and reporting was defined based on discussions with Stoller:

1) Obtain recent relevant digital data, plots, and reports from Stoller (or others) that present both recently observed surface water and ground water flow conditions and VOC contaminant distributions. Other contaminants, such as uranium (or other actinides) were not modeled as part of the former integrated flow and VOC fate/transport work and therefore were not updated in this effort.

2) Assess changes since closure (December 2005) based on actual data. Review and compare post-closure observed flow conditions against pre-closure flow conditions (i.e., Water Year [WY] 2000 data used in the former SWWB and localized flow models). Compare current post-closure surface flow gage and ground water level data with pre-closure conditions. If time and budget permits it, and the results of updated flow modeling indicate it is warranted, compare pre- and post-closure VOC distributions in both surface water and ground water. Note significant deviations.

3) Assess pre- and post-closure simulated flow conditions for both surface water and ground water flow systems against recent post-closure observation data at current post-closure monitoring points (i.e., surface water flow gages and ground water wells) for the different models outlined above. If warranted (as described above), compare simulated pre- and post-closure contaminant distributions in ground water against recently observed post-closure contaminant data. Note significant deviations, along with possible reasons why these deviations occur.

4) Discuss results of this initial data and former model performance evaluation with Stoller before proceeding with any modifications/updates to former models. Make model updates or modifications to former post-closure assumed data input (i.e., climate, land configuration details, and so forth) given time and budget limitations.

5) Assess updated model performance against observed post-closure data, and modify input to improve performance if necessary. Several factors affect the ability of any updated model to simulate post-closure conditions adequately. Where significant deviations between simulated and observed post-closure conditions are found, model input will be changed, to the extent possible and reasonable, to improve model simulation of post-closure conditions. The conceptual understanding and key factors affecting simulated flow conditions will be described for any significant deviations. Some of the more important factors are listed below:

    a) The quality and quantity (spatial and temporal) of post-closure data are considerably less than pre-closure conditions. This is consistent with the post-closure, compliance-based monitoring network, but it limits the ability to assess whether post-closure models are adequately capturing the true hydrologic and hydraulic response of the system. In addition, this also limits the ability to recalibrate these models if their results are not capturing true flow conditions adequately.

    b) Former simulated post-closure conditions were hypothetical in nature. For example, post-closure conditions were simulated by repeating the September 1999 to September 2000 15-minute precipitation data sequence for several years, until the integrated flow system response stabilized to imposed initial conditions. This limits the ability to compare actual observed post-closure conditions to previous simulated post-closure conditions.

    c) Other factors, such as not simulating actual closure configuration modifications as they occurred (over the years), limit the model's ability to capture the more short-term dynamic behavior of the system. The previous post-closure modeling assumed stabilized hydrologic conditions (i.e., years after closure), well after the effects of localized disturbances to the hydrologic flow system subsided (i.e., dust suppression water application, topographic changes, and vegetation changes). However, the current model updates were performed only a short time after closure, before the systems have fully stabilized.

3.0 Modeling Data Requirements

The following information was requested from Stoller for the purposes of evaluating the current flow system and changes from pre-closure conditions, as well as updating former integrated models:

- Topography – This is a critical model update and typically has a direct impact on local flow conditions. These data were provided as 2-foot interval contours in an Arcview geographic information system (GIS) "line" shapefile with elevation attributes, and required conversion into a spatial grid using Arcview Spatial Analyst software.
- Seep and slump areas – Several Arcview shapefiles were provided showing all recently observed post-closure seeps and slump areas.
- Available post-closure continuous ground water level monitoring data (i.e., Troll data) were provided.
- Periodic ground water level measurements – Datasets of post-closure ground water well water level measurements were provided.
- VOC data – Periodic VOC concentration data (including location ID, coordinates, concentrations, and time) were provided.
- Surface water flow data at all gages – Spreadsheets of 15-minute interval flow data were provided.
- Surface water data – Surface water analytical data (including location ID, coordinates, concentrations, and time) were provided.
- Surface water channel configuration/operation modifications to weirs, dams, operations, pond bathymetry, or operations such as transfer amounts/dates or releases were not provided, although most of this information is associated with the A- and B-pond series, the present Landfill Pond, and C-pond. These were not part of this evaluation given the focus on VOCs, primarily within the former IA.
- Climate data – Unheated precipitation data at various surface water gage locations were provided. Temperature, wind speed, humidity, and solar radiation data were also requested, but the site climate station no longer exists. Details of data obtained from the nearby National Renewable Energy Laboratory (NREL) climate station in Golden are described in Section 4.0.
- Vegetation coverage – Former long-term post-closure simulations assumed fully established vegetation. The site vegetation was still developing as of May 2007; however, a map reflecting the post-closure vegetation density was provided.
- Extent of ponded water area immediately south of former Building 371 – A GIS shapefile was provided.

4.0 Post-Closure Data Evaluation

Several datasets were reviewed to assess differences between actual and assumed (based on closure design criteria) post-closure hydrologic flow conditions. Key datasets reviewed include the following:

- Land configuration changes:
  - Land surface topography;
  - Vegetation;

  - o Surface drainage;
  - o Seeps and ponded surface water areas; and
  - o Soils.
- External model stresses:
  - o Climate, including precipitation and potential evapotranspiration (ET) (PET) input data.
- Hydrologic and hydraulic data:
  - o Ground water; and
  - o Surface water.

A brief review of these datasets as they relate to developing a defensible conceptual and numerical model is described below. Specifically, the review of data focuses on the following:

- Data quality and quantity as needed to develop models; and
- Deviations in trends from former datasets used as the basis for developing both pre- and post-closure model input.

<u>Land Configuration Changes</u>

Land Surface Topography

The post-closure land surface topography has changed since the integrated flow models were last updated in September 2005 (the "as-built" topography differs slightly from the design topography). Closure is defined as October 15, 2005 (contractor's declaration of completion) and December 7, 2005 (DOE's acceptance of declaration). The latest post-closure topographic surface was provided as 2-foot contours derived from a high-resolution flyover image taken in June 2006. The 2-foot contour Arcview shapefile was converted into an Arcview 3.3 surface grid format using Spatial Analyst software. This surface grid was then subtracted from the September 2005 (design release 12) closure topographic surface in GIS to show the spatial change in elevation. Results are shown on Figure 4.

Results of the topographic comparison indicate only localized areas of change. These include areas around former Building 371 (most notably an increase in elevation on the northeast side), the borrow-pit area just west of the former IA (a 10- to 20-foot decrease in elevation [the pit was enlarged to provide additional fill material elsewhere]), both increases and decreases just south of the former Building 881 area, slight increases (less than 10 feet) in the Building 400 area, and both increases and decreases in the OLF area mainly due to modifications in surface drainage.

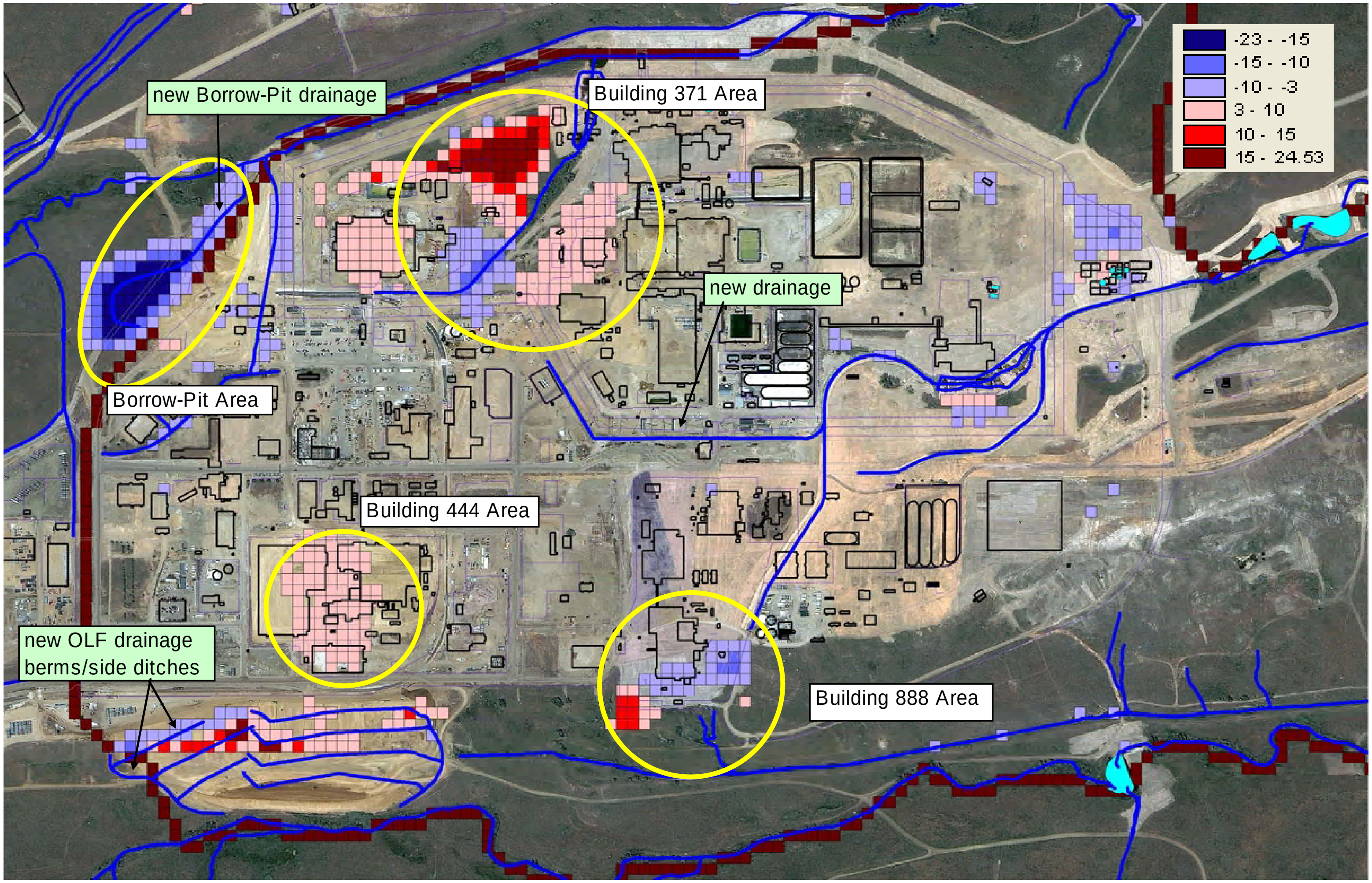


Figure 4. Change in surface topography (feet) between September 2005 closure plans (Site grading plan, design release 12) and actual post-closure conditions in 2006. The dark red squares represent the IA VOC model boundary. Red areas indicate an increase in actual surface elevation relative to plans, and blue areas indicate a decrease in actual surface elevation relative to plans. Cell sizes shown are 60 feet by 60 feet. Surface drainage is shown with blue lines. Photo background is from prior to closure.

Vegetation

The vegetation types and coverage densities across the Site are important in influencing the amount and locations of actual ET (AET). Former post-closure simulations assumed a uniform vegetation type (xeric) in all reconfigured areas, primarily over the former IA. Vegetation coverage over nonmodified areas remained variable based on preexisting vegetation coverages. This was documented in the former SWWB modeling (K-H, 2002).

Current (as of spring 2007) vegetation distributions and coverage densities over the reconfigured areas of the former IA were provided by Stoller, and are shown on Figure 5. Current coverage densities as a percentage of fully established vegetation densities range from 10% to nearly 70%. Much of the former IA remains well below 50% of fully established coverage densities, particularly over the OLF where it is approximately 20%. These low densities suggest that less water is lost to transpiration, which, despite being partially compensated by increased soil evaporation, would cause ground water levels to increase compared to a scenario where vegetation is fully established. For actual conditions, many of the revegetated areas were in fact former impervious paved areas or building sites. Thus, whether actual ground water levels increase is determined by a combination of a number of factors compared to pre-closure conditions (i.e., the elimination of leaky pipe inflow, post-closure precipitation, reconfigured soil compaction, AET rates, and the reconfigured surface topography).

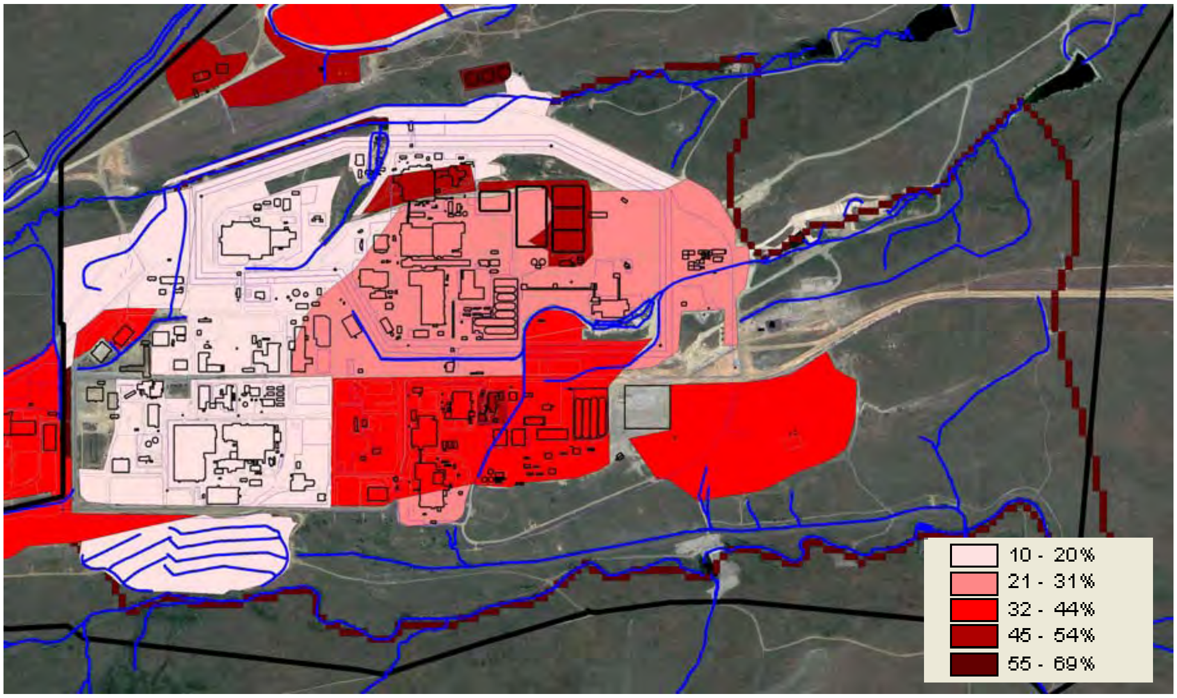


Figure 5. Current (spring 2007) vegetation coverage densities.

The actual vegetation coverage densities over regraded areas are considerably less than nearby fully established densities on similar slopes. This will result in less overall ET and a greater percentage of soil evaporation compared to plant transpiration and interception. This is a complex hydrologic process and it is difficult to adjust appropriate parameter values to represent the actual condition. For example, although crop coefficient values can be scaled based on coverage densities, the leaf area index (LAI) values and root depths with time probably also contribute to AET losses. Ultimately, however, the lack of fully established vegetation will reduce overall AET losses, causing local ground water levels to increase.

Surface Drainage

The current surface drainage within the former IA is largely the same as former post-closure assumptions (September 2005). The main modifications are shown on Figure 4, and are located in the OLF area where surface berms and side drainage ditches were constructed, and in the central former IA where a pre-existing surface drainage ditch was retained, extending from approximately the former Building 707 area directly east to where it connects with Functional Channel 4 (FC-4). Also, the additional excavation at the western end of the borrow pit just west of former Building 371 (FC-1) shows a surface drainage feature at the toe of the slope that intercepts the drainage feature at the eastern edge of the pit (which was included in previous model simulations). These surface drainage features do not constitute major changes to the site and are not expected to produce any significant hydrologic changes to the system over what was previously simulated.

Seeps and Ponded Surface Water Areas

Numerous seep areas had been previously mapped throughout the former IA as shown on Figure 6, although most of these seep areas remained inactive during previous modeling (1999 through 2005). Some of these seeps were occasionally active during more intense annual precipitation periods, typically in the spring time. Inspection of aerial photos prior to site development (photos from 1930s and 1950s) indicated many of these seep areas existed prior to development. Natural seep areas often occur in slump areas, along steeper hillslope areas. Ground water is forced out at seep areas, where bedrock has been exposed along the slump surfaces.

After Site closure, several new slumps, seeps, and ponded surface water bodies developed within the former IA. Active seeps during spring 2007 were noted in the FC-1 borrow pit area, OLF area, FC-2, FC-4, and 881 Hillside area (yellow and black circles on Figure 6). Stoller provided these seep locations in an Arcview shapefile coverage. Information was also provided on several new or recent slumps in the former IA, specifically in the OLF area, on the south side of FC-4 near former Building 991, and northeast of the former Solar Ponds, as shown on Figure 6 (red lines). (Note: The slump area near the former Solar Ponds pre-dates closure.)

Most of the new seeps are not related to slumps; however, seeps have developed at the large slump south of FC-4, and in the OLF along the more recently constructed lower western and eastern drainage ditches. The large slump associated with FC-4 is related to the removal of the French drain outlet (previously designated as surface water sampling point SW056), which appeared to provide continuous ground water drainage into the channel. Other seeps appear to be associated with land configuration modifications, such as changes in surface elevation (e.g., FC-1 borrow pit). It is possible that new seeps in the 881 Hillside, or along FC-2 areas shown on Figure 6, may simply be remnants of dust-suppression water, or possibly leaky subsurface utilities/corridors left in place. These areas typically occur where surface topography is eroded into or is near the weathered bedrock surface. The lower hydraulic conductivity of the underlying bedrock compared to overlying unconsolidated material forces ground water to discharge at the surface.

Seep development in the OLF is addressed in a separate post-closure hydrologic assessment and model update memorandum specific to this landfill.

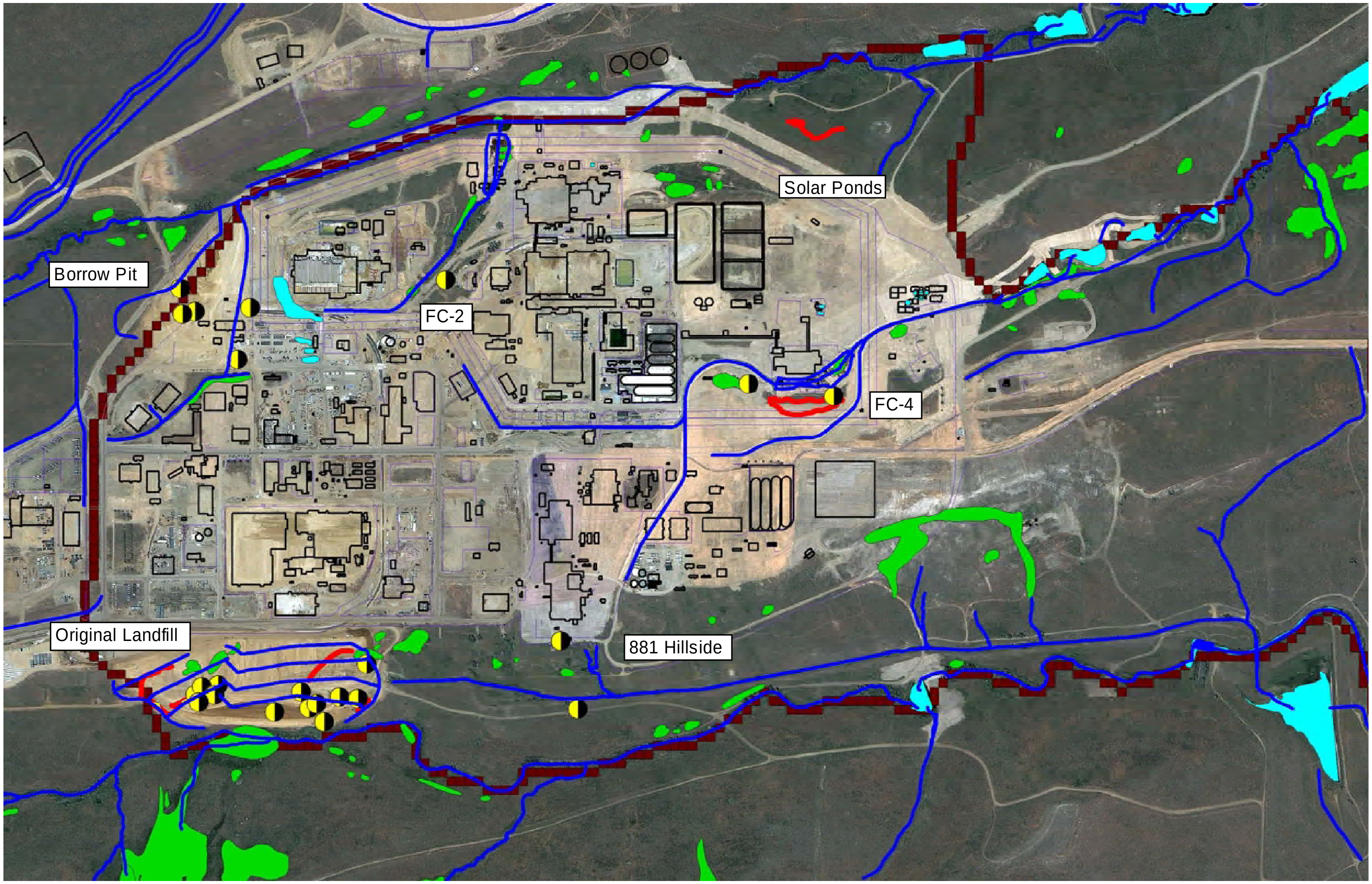


Figure 6. Pre- (green) and post-closure (yellow and black circles) seep locations, recent and post-closure slumps (red lines), and surface water ponds (light blue). The dark red cells represent the IA VOC model boundary. Most pre-closure seeps shown were not active during previously modeled period (1999 through 2005). Although recent, the slump northeast of the former Solar Ponds was first observed prior to Site closure.

No information was provided on the rates of flow from any of the seeps, although the flow from OLF Seep #7 appeared to be well above 1 gallon per minute (gpm) during a May 2007 site visit. This may be due to the relatively high precipitation and snowfall during late 2006 and early 2007. Other seeps in the FC-1 borrow pit area did not show active surface discharge, but surface soils were moist.

Surface ponding has been observed just southwest of former Building 371, where there is a local depression in the surface topography. Water probably ponds here due to well-compacted surface soils and the lack of drainage from the area. Despite the potential overcompaction, the nearby seep in the FC-1 borrow pit to the west appears to be activated by slow discharge from the largest of the ponds via a shallow deposit of gravelly railroad ballast remaining from Site closure.

Soils

With changes in the surface topography, especially where fill dirt was added to the former topography (i.e., positive [red] areas on Figure 4), new soil types must be defined. For the purpose of this modeling update effort, any new soil fill was assumed to be Rocky Flats Alluvium. No other information on soil modifications were provided, or are known at this point.

<u>External Model Stresses</u>

Climate

Previous integrated flow modeling at RFETS relied heavily on the use of a high-quality climate dataset from October 1, 1999, through October 1, 2000. Essential climate data for modeling are precipitation, temperature, solar radiation, relative humidity, and wind speed. The last four data types are used to calculate PET rates at the site, which is subsequently included in the model as input.

Previous evaluation of RFETS pre-closure climate data indicated the following important characteristics for precipitation:

- Data showed that annual precipitation across the RFETS site varied spatially by more than 100% based on available local gage data.

- Durations of most precipitation events are very short (i.e., less than 1-hour duration). As a result, reproducing the resulting hydrologic response requires good characterization of the short-term precipitation data (i.e., over hours, not 1 day).

As a result, precipitation data were carefully developed for the 1999 to 2000 time period, and later for the validation period of 2000 to 2001, using NREL meteorological (met) station data and local RFETS measurements at multiple monitoring points with non-snow-melting precipitation gages. SWEs were calculated for the RFETS data using the met station heated precipitation gage data. These RFETS data were spatially distributed and collected every 15 minutes.

In addition to the precipitation data, a considerable effort was made to calculate PET at hourly time intervals. It was essential that the PET was calculated based on accurate and complete wind speed, solar radiation, relative humidity, and temperature data so that it could be synchronized with the 15-minute precipitation data. For example, when precipitation events occur, the cloud cover and typically cooler temperatures reduce the PET temporarily and this in turn reduces the AET.

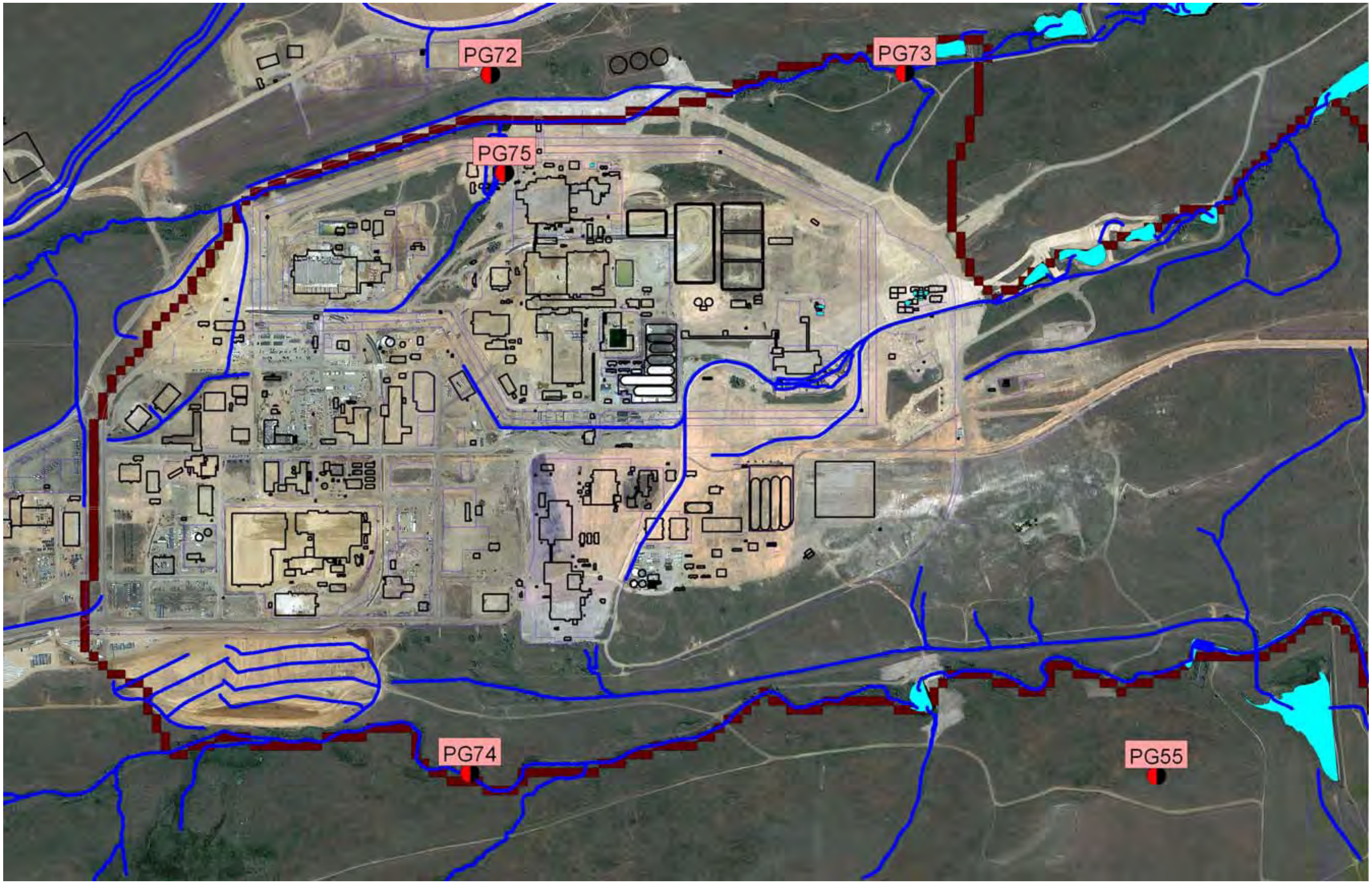


Figure 7. Site precipitation gage locations (unheated). Photo background is from pre-closure. PG75 is a planned replacement for PG72.

It was important to carefully prepare accurate spatially and temporally synchronized precipitation and PET datasets. Although time consuming, this is one reason why the former pre-closure model was able to reproduce both the surface water and ground water system responses so well.

Unfortunately, the post-closure climate data are not available for the Site at a similar quality and quantity as for pre-closure. Although precipitation data are still collected at a number of site locations, the precipitation gages are unheated and therefore winter SWEs cannot be determined. Figure 7 shows the locations of the current precipitation gages.

Precipitation data at only one gage were evaluated, and this was only for rainfall precipitation, not SWEs because of unheated gages. Monthly precipitation totals at gage PG72 for 2005 to 2006 are compared in Figure 8 to the former October 1999 to October 2000 time period used to drive previous integrated flow modeling. From this plot it is clear that precipitation during the former 1999-2000 time period for most months was considerably higher than for the 2005-2006 time period. Only non-snow months (May through September) can really be compared.

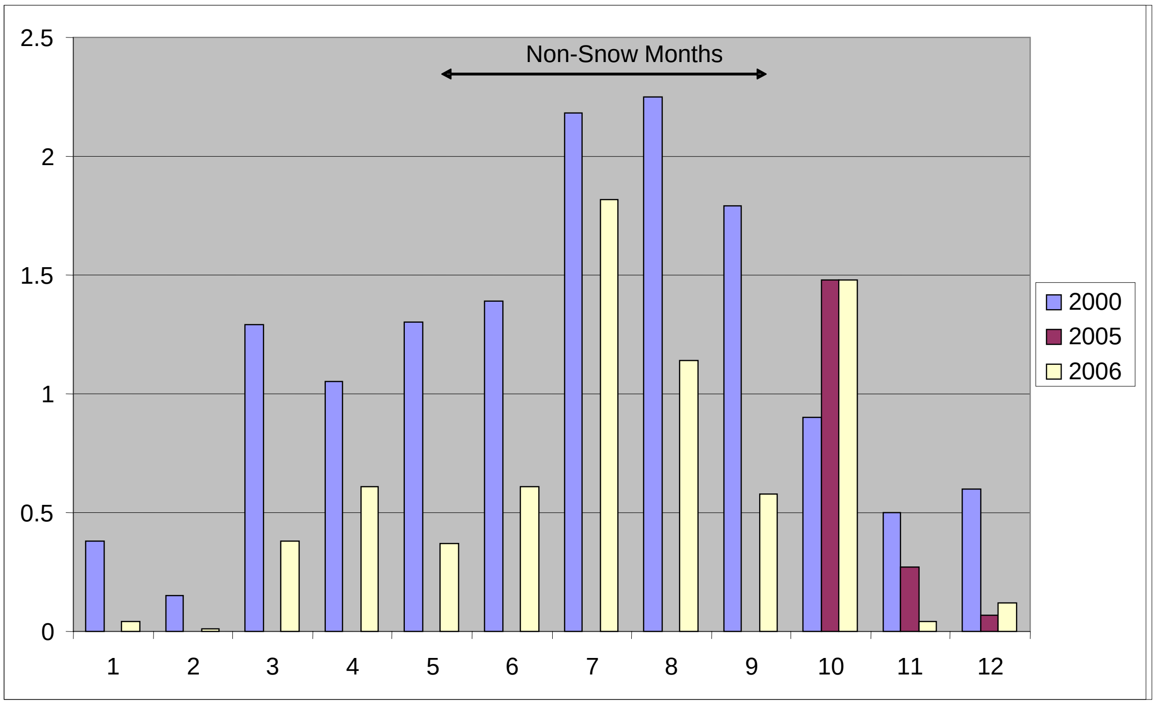


Figure 8. 2005/2006 monthly precipitation totals (inches) for precipitation gage PG72 compared to Year 2000 months (given on x axis – 1 represents January). Data are only shown from 10/2005 through 12/2006 for PG72 because this represented the simulated time period. Data for Year 2000 months are from the former site climate station (heated gage), so measurements for the winter months are much higher than the unheated PG72 measurements.

The difference between Site precipitation data for the 1999-2000 and 2005-2006 time periods suggests that post-closure ground water levels and surface flow/levels could be lower compared to long-term projections from the former 2005 integrated models that utilized the 1999-2000 climate data. However, the limited quantity and unheated local precipitation gage data over the hydrologic year prevent using it to develop detailed model input for the post-closure time period. Rather than attempt to use the Site's unheated gage precipitation, the nearby NREL climate station data were used to drive the model simulations to assess post-closure hydrologic conditions with the updated integrated flow model. Details of the collection, synthesis, evaluation, and conversion of these data into model input are described in IHS's July 2007 memorandum to Stoller that summarizes results of the OLF model updates and evaluation.

Figure 9 summarizes monthly precipitation data and calculated PET based on several climate parameters provided in the NREL data from late 2002 through May 2007, and former Site gage data from 1999 to 2000. No NREL data are shown for October 2000 through October 10, 2002, because they had errors. Figure 10 summarizes the annual precipitation by year, and Figure 11 shows a comparison by year of precipitation from October through January to help explain the difference in precipitation during this period.

Results of these data show that the October 2006 through January 2007 period had nearly twice the amount of precipitation as previous years. In addition, the cumulative PET over this same time period remained relatively low. The combination of higher precipitation and lower PET likely promoted higher recharge rates to the ground water flow system in winter/early spring 2007. This can be seen in areas such as the OLF, for example, where a number of seeps have been observed. Despite this higher period of precipitation, the annual precipitation amounts (Figure 10) indicate 2005 and 2006 were largely the same (~15 inches) as the 1999-2000 time period. The 2004 annual precipitation was approximately 40% higher (~21 inches) and 2003 was approximately 50% less than the 1999-2000 time period.

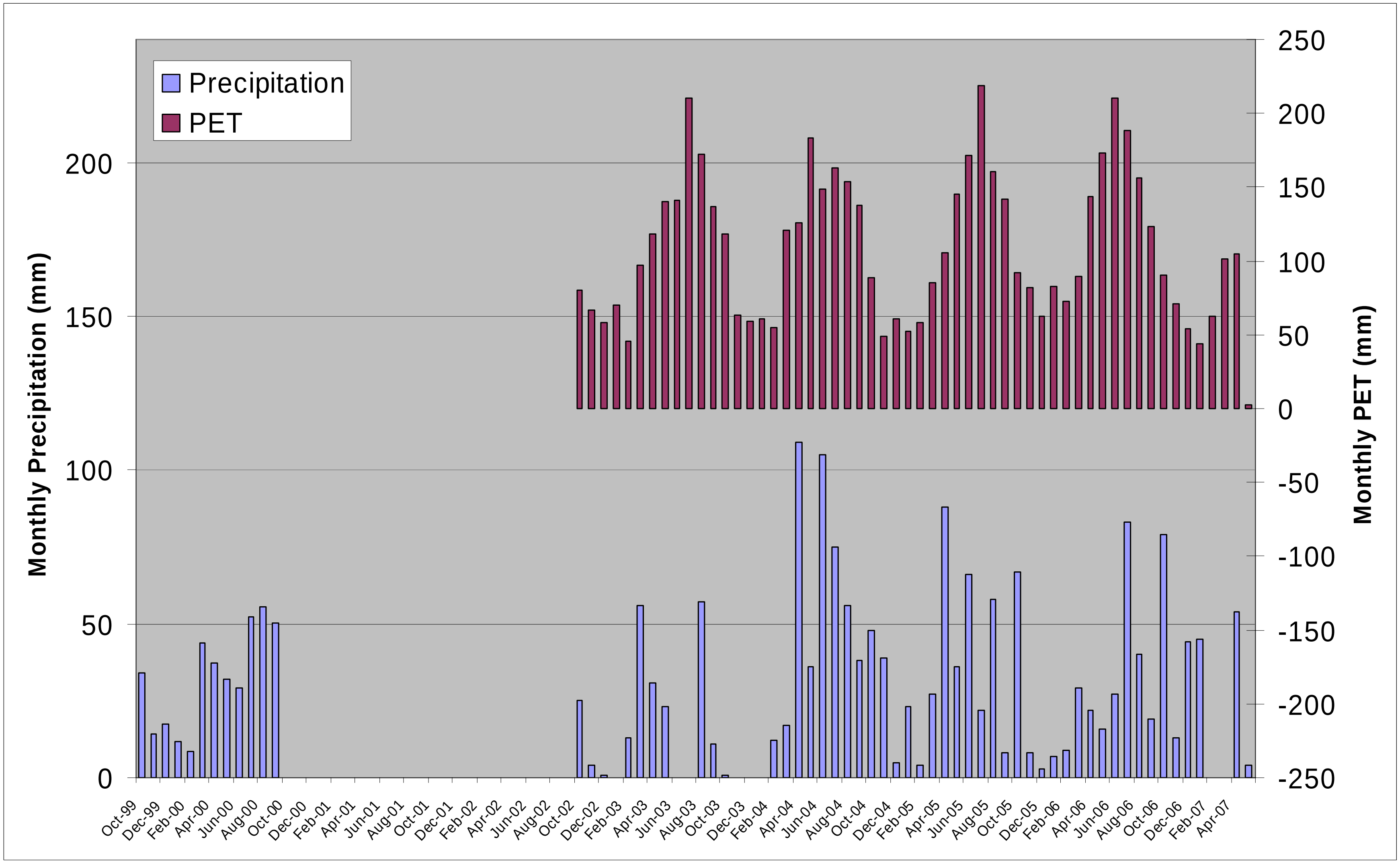


Figure 9. Monthly precipitation and calculated PET data based on NREL wind station data for late 2002 through 2007. The 1999 to 2000 data are from a combination of actual Site surface water gage data and the former Site climate station. Precipitation data for 2003 may be low.

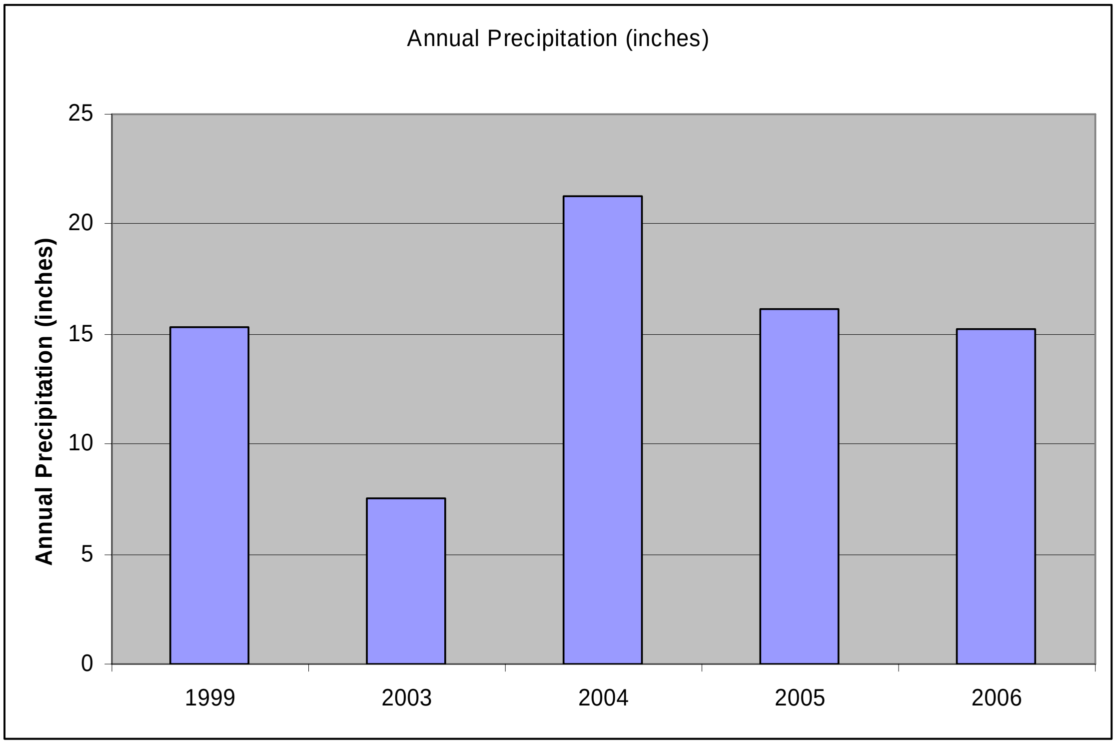


Figure 10. Annual precipitation (inches). All data are from the NREL station, except 1999 data which are based on a spatial average of actual Site data.

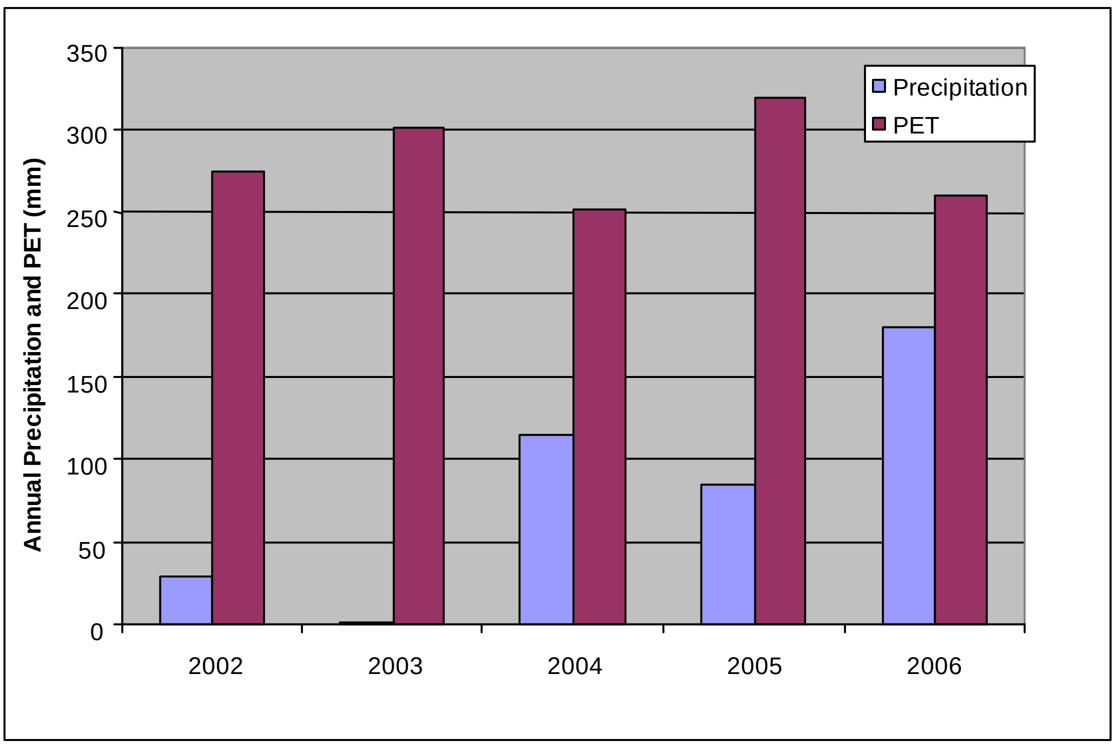


Figure 11. Comparison of total precipitation and PET from October through January each year based on NREL wind station data.

Hydrologic and Hydraulic Data

Ground Water

Data from continuously monitored and quarterly measured ground water levels were obtained from Stoller for post-closure conditions. The quantity of wells has been significantly reduced, which in turn affects the ability to evaluate and understand the response of ground water levels and flow directions due to closure. In addition, many of the current (i.e., post-closure monitoring network) wells were installed sometime in 2005, and therefore present little or no "baseline" data that might highlight the change between pre- and post-closure conditions.

Figure 12 shows the locations of quarterly measured ground water wells. The colors represent the change in average annual ground water levels from the October 1999 – October 2000 (pre-closure) time period relative to the October 2005 – October 2006 time period (post-closure). Red colors indicate an increase (rise) in ground water levels (in feet), and blue colors indicate a decrease. Yellow indicates that little change in water level (i.e., less than 3 feet) has occurred between pre- and post-closure.

Most areas indicate increases or decreases in levels of less than 10 feet. The former Building 771 and 444 areas, for example, show an average annual decrease in levels, while others such as former Buildings 371 and 881 and the former Solar Ponds area indicate a general increase in levels. Ground water levels in areas not heavily modified during Site closure, such as east of the 903 Pad and in the mesa area just upgradient of the East Trenches Plume Treatment System (ETPTS), changed little (i.e., less than 3 feet), as expected. This lack of change in unchanged areas suggests that the diminished precipitation for the 2005-2006 time period compared to 1999-2000 may not have impacted ground water levels much, especially in deeper ground water areas.

The relatively small change in ground water levels suggests that general flow gradient directions remain largely the same as predicted by the former post-closure models. Locally, for example near or at former building locations where soils were placed over building remnants and subsurface drains were disrupted or removed, directions of flow could be altered. However, at the scale of the IA, flow directions over pre-existing VOC plume areas are not considered to have changed, especially given the relatively small changes in ground water levels. Note that the spatial resolution of available quarterly monitored data is not sufficient to capture all of the surface water features and remaining subsurface features, and does not justify preparing potentiometric surface maps for either the unconsolidated or bedrock stratigraphic units.

The post-closure continuous ground water level monitoring data provided (Figure 13) are of limited value mainly because few continuous records exist that fully encompass pre-closure through post-closure (i.e., pre-December 2005 through May 2007, including enough of the early data to establish a "baseline"). Many wells that were continuously monitored prior to closure were abandoned in 2005, while others were installed in 2005. In addition, after careful review of available continuous water level data from which obvious outliers were removed by Stoller, many of the data indicate significant discontinuities, where water levels rapidly rise or drop over a very short time frame. While some of these are clearly due to sampling events (i.e., rapid declines followed by slow asymptotic recovery), many cannot be explained and as a result the data quality is suspect.

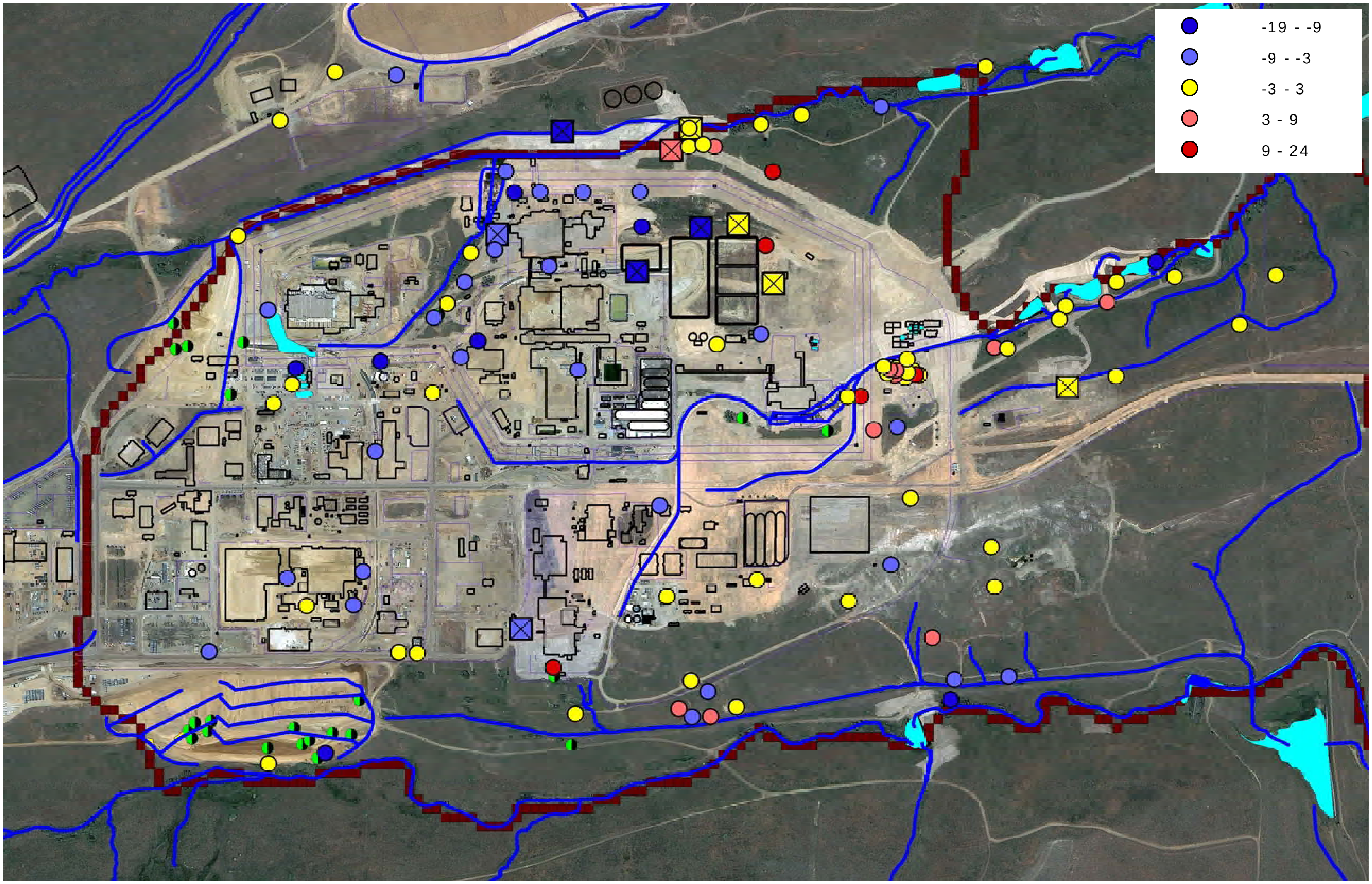


Figure 12. Approximate change in average annual ground water levels (feet) from (October) 1999-2000 to 2005-2006. Circles are wells screening unconsolidated materials, and squares are wells screening bedrock. Photo background pre-dates Site closure. Light blue features indicate surface water; note several puddles south of former Building 371, as described in the text. Black-green circles are post-closure seep areas.

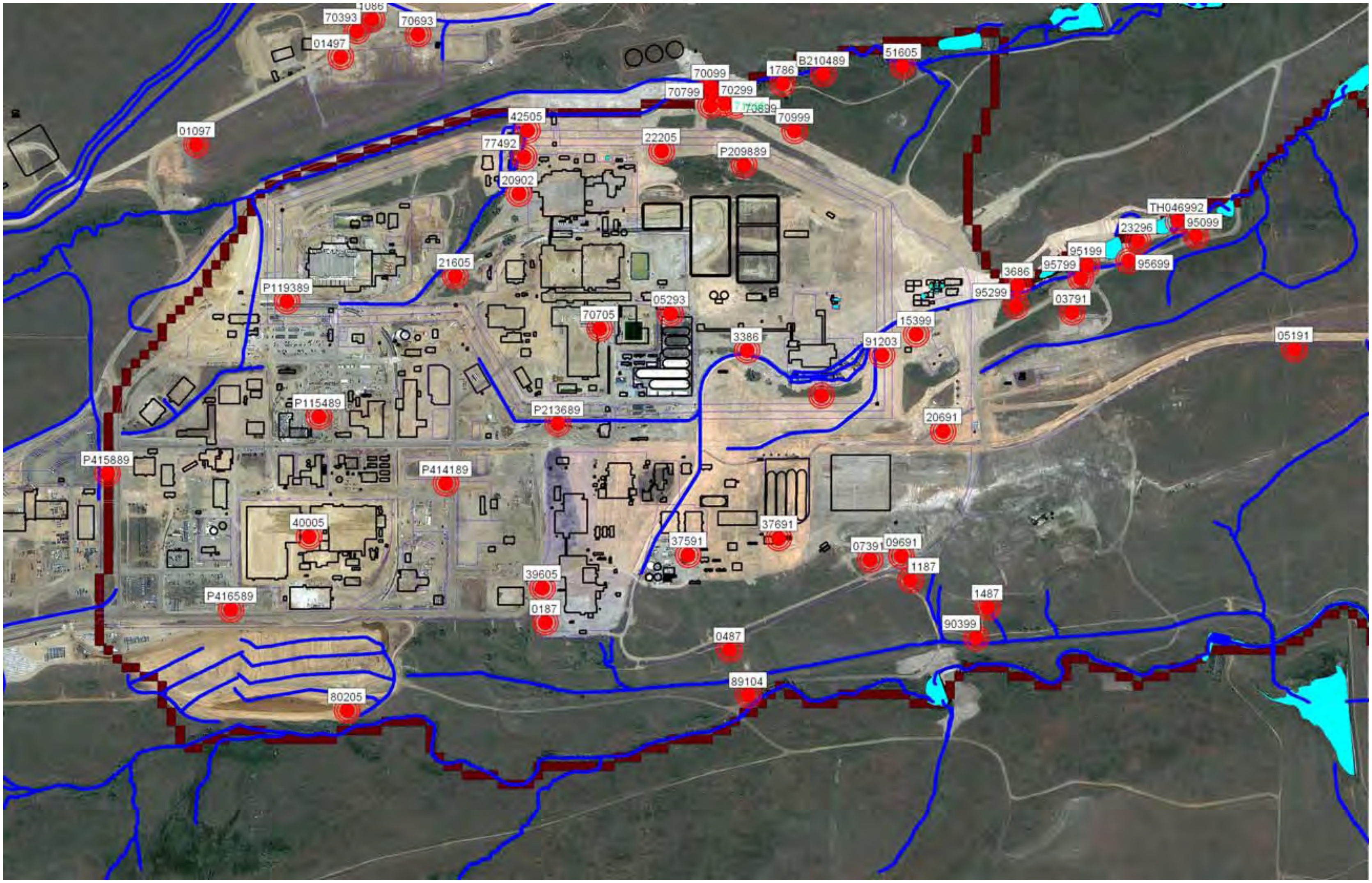


Figure 13. Locations of continuously monitored ground water wells through time in the IA. Most of those shown no longer exist. Photo background pre-dates closure.

Despite the limitations of using the continuously monitored data, a review of wells with post-closure data does not generally indicate clearly increasing or decreasing trends that might be attributed to Site closure. Most of the change in ground water levels can be attributed to the significant variability in climate from 2002 through May 2007, as indicated earlier.

Surface Water

Only those surface water flow gage locations shown on Figure 14 can be compared against simulated flow because they lie within the IA VOC integrated flow model boundary indicated by the dark red squares. Locations GS51, SW018, GS10, and SW027 record surface flows in the channels shown. The remaining locations, ETrSys, Mound Sys, and SPPSys, reflect effluent flow data for the ETPTS, MSPTS, and Solar Ponds Plume Treatment System (SPPTS), respectively.

Review of post-closure surface water flow data (Figure 15) from October 2005 through May 2007 indicates that flow was recorded in each of these gages. SW027, along the South Interceptor Ditch (SID) just upstream of Pond C-2, flowed only during February, March, and April 2007. This flow was in response to a combination of direct runoff, relatively high ground water recharge, and subsequent surface discharge caused by the significant precipitation events from October 2006 through January 2007 (Figure 11). Higher flows also occurred in SW018 (FC-2) and GS10 (FC-4) over the same time period, although the flow record at SW018 is incomplete. The observed range of baseflow in GS10 (~2 to 5 gpm) is lower than pre-closure flows (~24 to 31 gpm during 1999-2000), while the partially complete data from SW018 suggest post-closure baseflows were more variable (~5 to 15 gpm). Although no gage existed at SW018 during 1999-2000, previous simulations of pre-closure flows at this location were approximately 5 gpm. A peak flow of 543 gpm occurred at SW018 on April 24, 2007, and three times since closure flows exceeded 200 gpm. At GS10, flows exceeded 300 gpm for 6 days, and peaked on April 24, 2007, at 5,419 gpm. It is unclear what produced the relatively high post-closure baseflow rates at SW018, where it was expected that removal of pavement in the area would have reduced the overall inflow (i.e., fast runoff) to FC-2. The additional flow may be from increased ground water discharge through backfill material associated with former subsurface utility corridors and piping (not accounted for in the integrated flow model), combined with the continuing drainage of dust-suppression water.

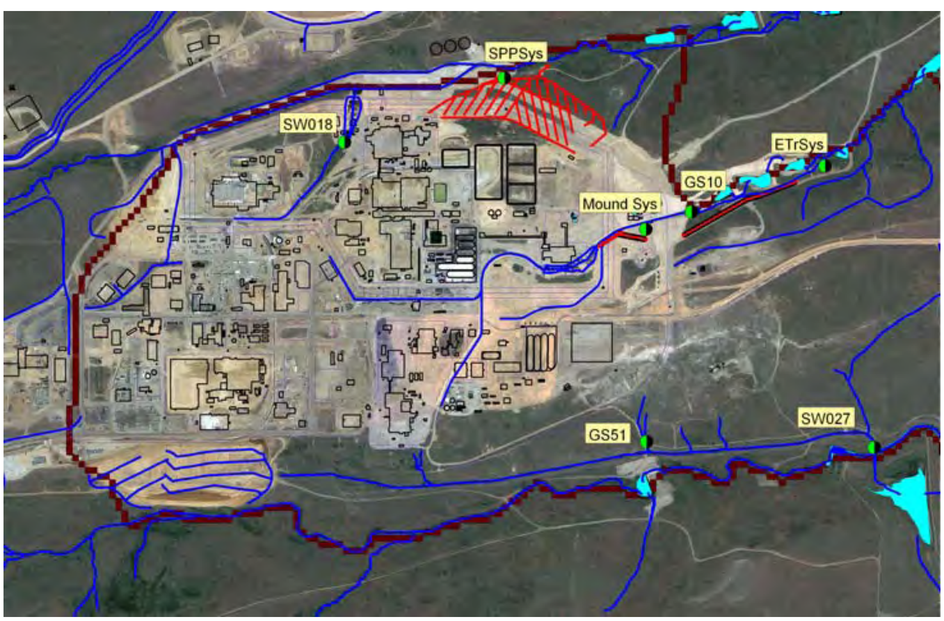


Figure 14. Surface water flow gage locations within the IA model boundary. Photo background pre-dates Site closure.

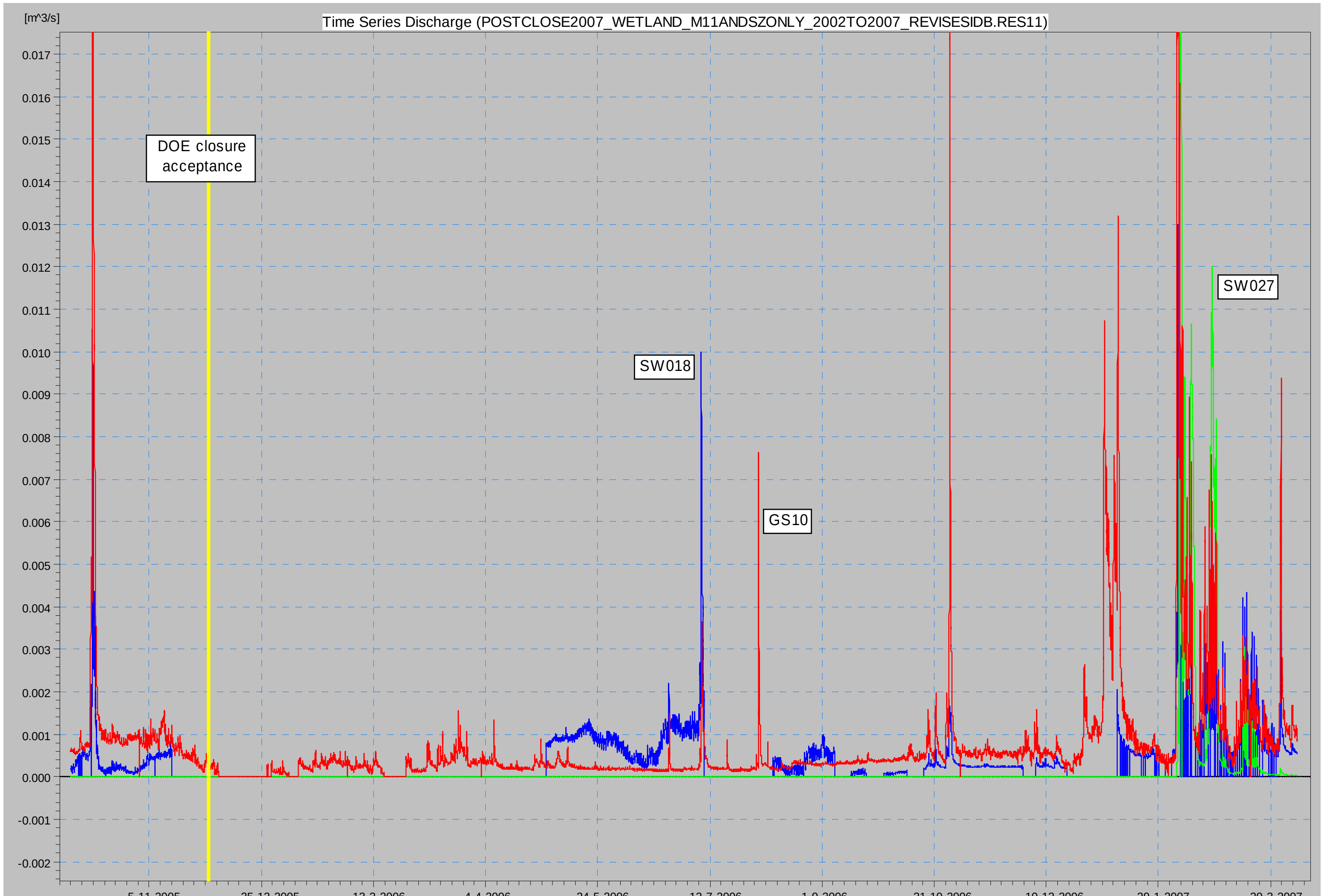


Figure 15. Post-closure surface flow (m^3/s) at gages GS10 (South Walnut Creek), SW018 (FC-2), and SW027 (SID). (Note that 1 m^3/s equals 15,837 gpm.) Dates are shown using day-month-year convention. Note episodic flow at SW018 (blue curve), near-continuous flow at GS10 (red), and lack of flow at SW027 (green) until fall/winter 2006.

Post-closure surface water flow rates clearly declined compared to pre-closure rates. For example, pre-closure annual flow through GS10 (1999-2000) was approximately 4.1 x 10^7 gallons per year (gal/yr), while average annual post-closure flow (October 2005 to October 2006) was only approximately 3.7 x 10^6 gal/yr. This represents nearly a 10-fold reduction in flow. This reduction is mostly due to the removal of the Sewage Treatment Plant (imported water) contributions and a significant reduction in surface runoff from impervious surfaces. Variability in peak flow response is also reduced. This is likely due to the combined result of impervious surface and culvert removal, addition of rip-rap, and added surface storage in the wetlands upstream in FC-4.

Results of former post-closure simulations, documented in the September 2005 "Summary of Hydrologic Flow and Fate and Transport Modeling Conducted at the Rocky Flats Environmental Technology Site," showed pre- and post-closure simulated annual flows at SW027 being 8.0 x 10^6 gal/yr and 7.0 x 10^5 gal/yr, respectively. This represents a reduction to less than 10% of pre-closure flows in the SID. Former modeling also showed that surface water flow within the SID was sensitive to ground water levels along the ditch margins. The fact that surface flows at SW027 were recorded for a sustained period of time (February and March 2007) while no other flows were recorded otherwise suggests this is mostly due to snowmelt runoff and temporary discharge of ground water along the SID caused by higher ground water levels. Former model input probably does not accurately reflect local hydrogeologic conditions along the SID, or the SID profile based on former surveyed sections, to adequately capture the actual flow characteristics reflected in observed flow data.

Observed post-closure effluent flow data are also available for the SPPTS, ETPTS, and MSPTS as indicated on Figure 16. Effluent flows, measured at the effluent manhole flumes, are largely similar to pre-closure conditions with the exception of the MSPTS, which increased approximately 10-fold due to a tie-in of a storm drain corridor to the interceptor trench. These data also indicate a notable increase in discharge from the ETPTS during late summer 2006. Based on communication with Stoller, this is erroneous; alternate flow measurements (from data collected by instruments housed in the instrument vault installed in 2006) indicate the average flow over this period was approximately 0.8 gpm. Otherwise, manhole flume flow data for these systems indicate flow rates were relatively stable throughout the year and averaged approximately 1 gpm for the SPPTS and MSPTS, and approximately 2 to 3 gpm for the ETPTS. Fluctuations can be largely attributed to seasonal variations in climate, ground water recharge, and AET.

5.0 <u>IA VOC Model Updates</u>

After review of available post-closure data, assessment of changes due to closure, review of former long-term post-closure flow modeling results, and discussion with Stoller about immediate needs, the following models were updated:

- IA VOC flow model;
- OLF model; and
- MSPTS model.

As noted previously, this memorandum summarizes updates to the IA VOC flow model that reflect post-closure configuration modifications to the system. Changes to the model input for the OLF and MSPTS models are described in more detail in two concurrent, but separate, memoranda. Areas external to the IA VOC flow model were not evaluated due to relative importance (the VOC model area encompasses VOC plumes of interest) and time constraints. In addition, VOC concentration data were not evaluated as part of this study due to the findings of the flow model.

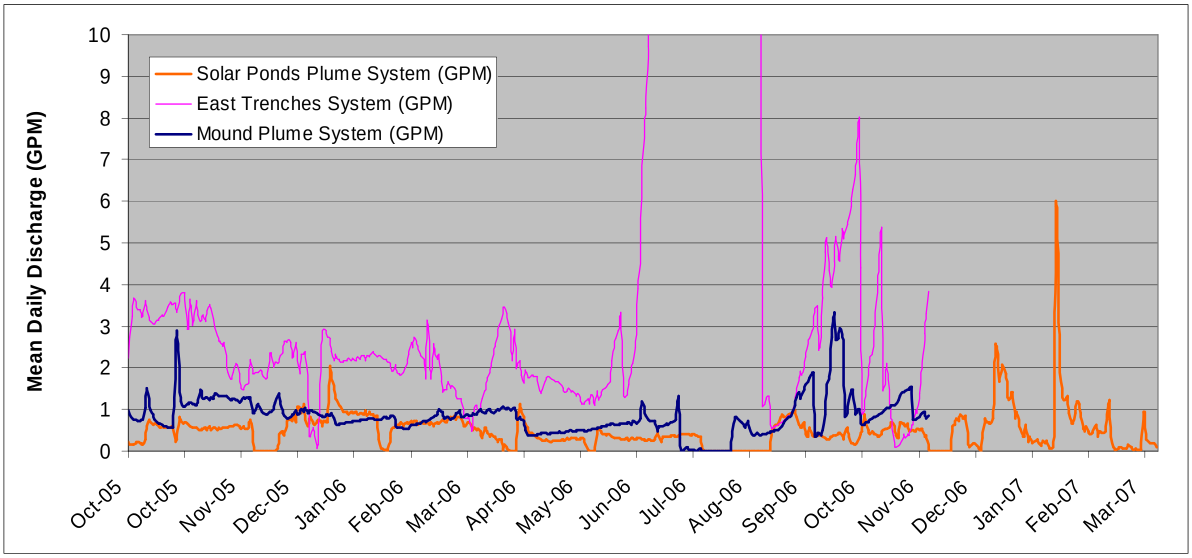


Figure 16. Post-closure mean daily discharge flow rates (gpm) for the ground water treatment systems. The flows shown for the ETPTS in June-August 2006 time period are not accurate; average flow over the period from May 15 through September 15, 2006, based on the instrument vault data rather than data from the manhole flume, was approximately 0.8 gpm.

The only major modification to the former post-closure IA VOC model configuration (last updated in September 2005) was updating the surface topography (Figure 4) and using post-closure climate data from the NREL station to generate a more realistic post-closure hydrologic and hydraulic response. This allows a more direct comparison between available observed post-closure hydrologic data and model-simulated conditions. The nearby NREL station climate data were used to develop a high-quality, continuous climate sequence from October 2002 through May 2007.

Minor changes were also made to the MIKE11 flow channel input to more accurately simulate infiltration and ET of water in the FC-2 and FC-4 wetland areas. This was done by specifying activation of the flood option in the MIKE11 network input file. Other minor surface water drainage features could also have been specified explicitly using the one-dimensional surface water channel flow model MIKE11. However, because the MikeSHE overland flow module calculates 2-dimensional surface flow based on the supplied surface topography based on a diffusive-wave approximation, many of the surface water drainage features not explicitly included as MIKE11 channels are adequately simulated in the model.

With regard to vegetation at the Site, the current vegetation coverage densities are far from fully established. The former post-closure model (Figure 5) assumed vegetation would be fully established. If fully established, the vegetation would cause greater ET-driven ground water loss from the unsaturated and ground water systems, which in turn would reduce ground water levels. Hence, the decreased post-closure vegetation coverage is expected to produce higher ground water levels, based on former modeling. Although it would have been more accurate to simulate post-closure flow conditions by specifying the time-varying vegetation coverage, this information was unavailable. In addition, the specification of ET parameters is complex and would have required an considerable time to undertake the careful and iterative process required to determine appropriate (i.e., calibrated) values for these parameters (i.e., LAI, root depths with time, interception storage for each plant type, crop coefficients with time, and several other more empirical parameters). As such, fully established vegetation coverage was assumed for the post-closure simulations conducted. In some areas, less than expected modeled flows (i.e., at SW018) can be partly explained by the assumption that vegetation is fully established.

Many different types of model output simulated by the updated post-closure IA VOC flow model are available. The following output is specifically discussed to address objectives stated earlier:

- Ground water levels:
    - Comparison of simulated to actual post-closure water levels;
    - Simulated surface seep areas; and
    - Simulated flow directions.
- Surface flow rates at gaged locations.
- Flow rates from passive ground water treatment systems.

<u>Simulated Ground Water Conditions</u>

Simulated ground water depths are shown on Figure 17, and the difference between mean simulated depths from October 2005 through April 2007 and observed mean annual levels based on quarterly measurements for available post-closure wells is shown on Figure 18. Results indicate several areas developed seeps, as previously noted, including the FC-1 borrow pit area in the northwestern part of the model area, FC-2, and FC-4. All three of these areas were predicted in former modeling to produce seeps, primarily due to the shallow bedrock that forces nearby ground water inflow to discharge at the surface from adjacent steeper slopes. Ground water depths generally increase away from surface channels, except in the central portion of the former IA (western FC-4 area) where depths are generally less than 5 feet below grade. Ground water depths are at least 20 feet over many former buildings (e.g., 444, 371, 881, and 771) and beneath the mesa extending east from the 903 Pad area.

Simulated ground water levels are generally within 3 feet of observed levels throughout the IA VOC flow model boundary. These differences are similar to previous model simulations of the 1999-2000 year. Notable deviations occur in groups of wells in the former Building 444 area, south of Building 881 and at the 881 Hillside French drain, generally along the FC-2 drainage, and in the western portion of the former Solar Ponds area. In each of these areas, ground water is oversimulated (i.e., simulated depths are higher than actual) between 3 and 9 feet, while in the Building 881 and 881 Hillside area water levels are both oversimulated and undersimulated by more than 9 feet in localized areas. This suggests that the measured water levels may be affected by residual infrastructure or other artifacts of closure. In the Building 444 and Building 881/881 Hillside areas, it is possible that ground water drains more freely than is simulated due to the continuing effectiveness of some subsurface pipelines and utility corridors. In the former Solar Ponds area, the weathered bedrock hydraulic conductivity values may be locally higher than in other areas, which would help drain away ground water from this area (i.e., lowering ground water levels more than predicted by the model). In both the former Building 444 and Solar Ponds areas, it is possible that surface soils were overcompacted and ground water levels decline because of lower surface infiltration and subsequent ground water recharge.

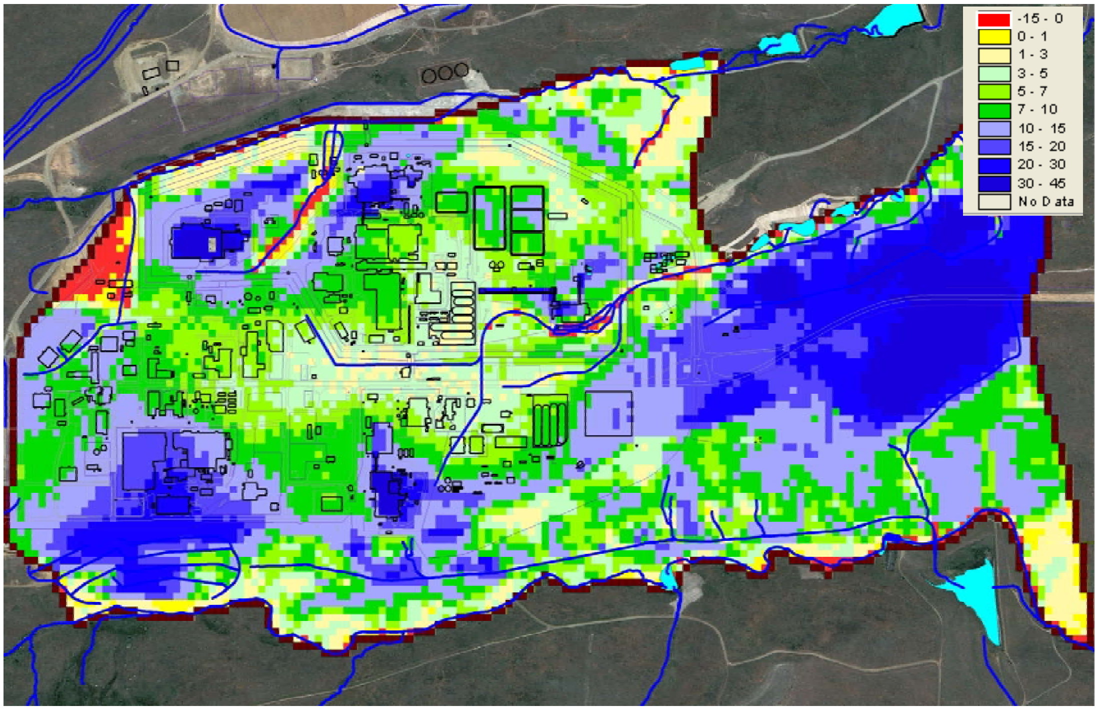


Figure 17. Average annual simulated ground water depths (feet below ground surface) (October 2005 to May 2007). Photo background is from pre-closure era.

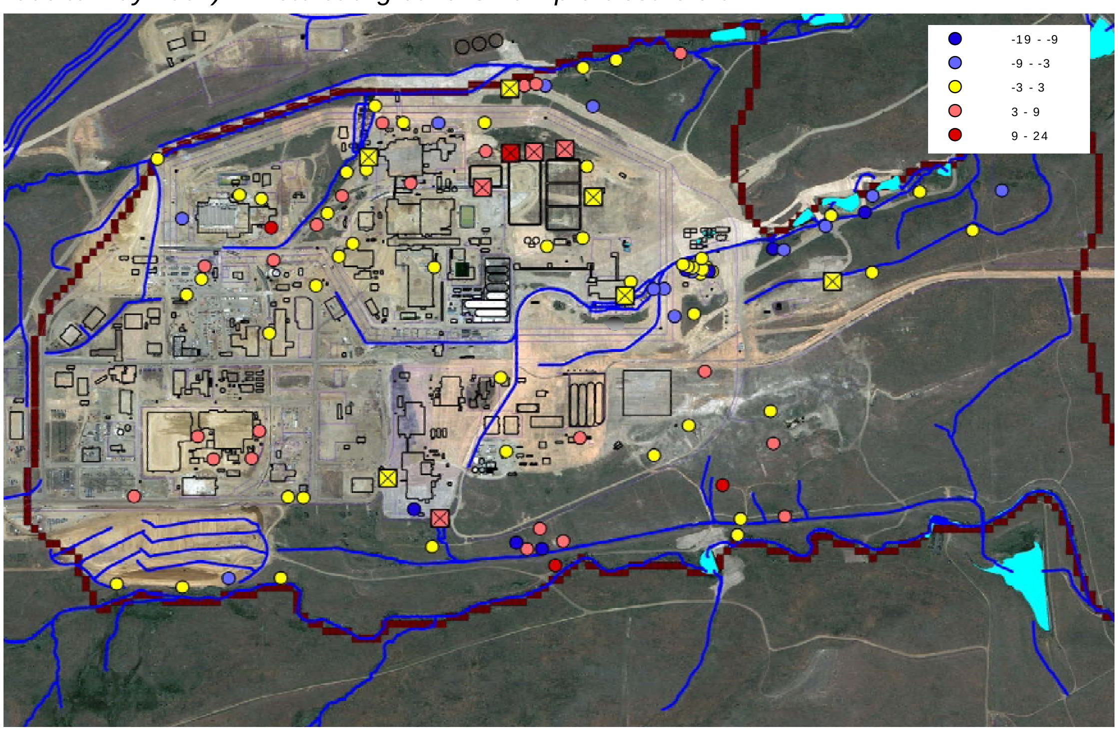


Figure 18. Difference between simulated post-closure average annual water level depths and observed average annual water levels (feet). Simulated depths shown in red (positive) are greater (i.e., ground water is predicted to be shallower) than observed, while simulated heads shown in blue (negative) are less (deeper) than observed. Circles represent wells screened in the unconsolidated material, and squares represent wells screened within the bedrock. Photo background is from pre-closure era.

One area in both the current and former post-closure models that deviates from actual post-closure (2005-2007) hydrologic conditions is the borrow pit (FC-1) west of the former Building 371 area. Former pre-closure (September 2005) evaluation of this area indicated borrow pit excavation depths would intercept the weathered bedrock surface (based on excavation plans and borehole information) and cause ground water to seep out around the edge and on the bottom of the pit, just above the weathered bedrock (Figure 17). However, a visit to this area (May 14, 2007) revealed only surface wetness in some areas, but no significant continuous baseflow that could be attributed to intercepted bedrock (Figure 19). No ground water monitoring wells or surface flow gages are located within FC-1; the closest wells are at the northern junction of FC-1 and North Walnut Creek, and east of the pit on the western edge of the Building 371 area. Given the very low vegetation coverage (Figure 5) in this area and the relatively high October 2006 through January 2007 precipitation (Figure 11) that has clearly led to increased seepage throughout the OLF, the lack of seepage in the borrow pit is surprising. Several factors could cause this, including an incorrect final surface topography, ill-constrained previously interpolated bedrock surface for the area, or overcompaction of surrounding soils that would promote runoff over recharge. Hydrologic conditions in this area do not affect existing VOC plumes in the former IA.

Figure 19. FC-1 borrow pit area (May 14, 2007). View is from southern Building 371 area to the northwest across the pit.

Simulated post-closure ground water elevations shown on Figure 20 are compared against data from several observed continuously monitored ground water wells. Results show that simulated levels and amplitudes compare well with observed data at most locations, although there is little overlap in time between the observed and simulated data. Simulated ground water response does not reflect actual dynamics well in the Building 444/OLF area and south of the former Building 881 area, probably because the subsurface complexity is not captured well in the model.

<u>Simulated Ground Water Flow Directions</u>

Ground water flow directions are important in assessing possible changes to the long-term contaminant migration directions and possible surface discharge. Evaluation of inter-annual (year to year) and intra-annual (seasonal) variability in ground water levels for pre-closure suggested relatively uniform temporal fluctuations in levels throughout the Site, which in turn implies relatively uniform flow patterns and directions. In other words, ground water levels in most Site wells rise similarly in response to precipitation recharge, and then decline due to the combined effects of ET and drainage. Despite the spatial differences in seasonal ground water level increases/decreases, no major ground water mounds or sinks were created in the post-closure

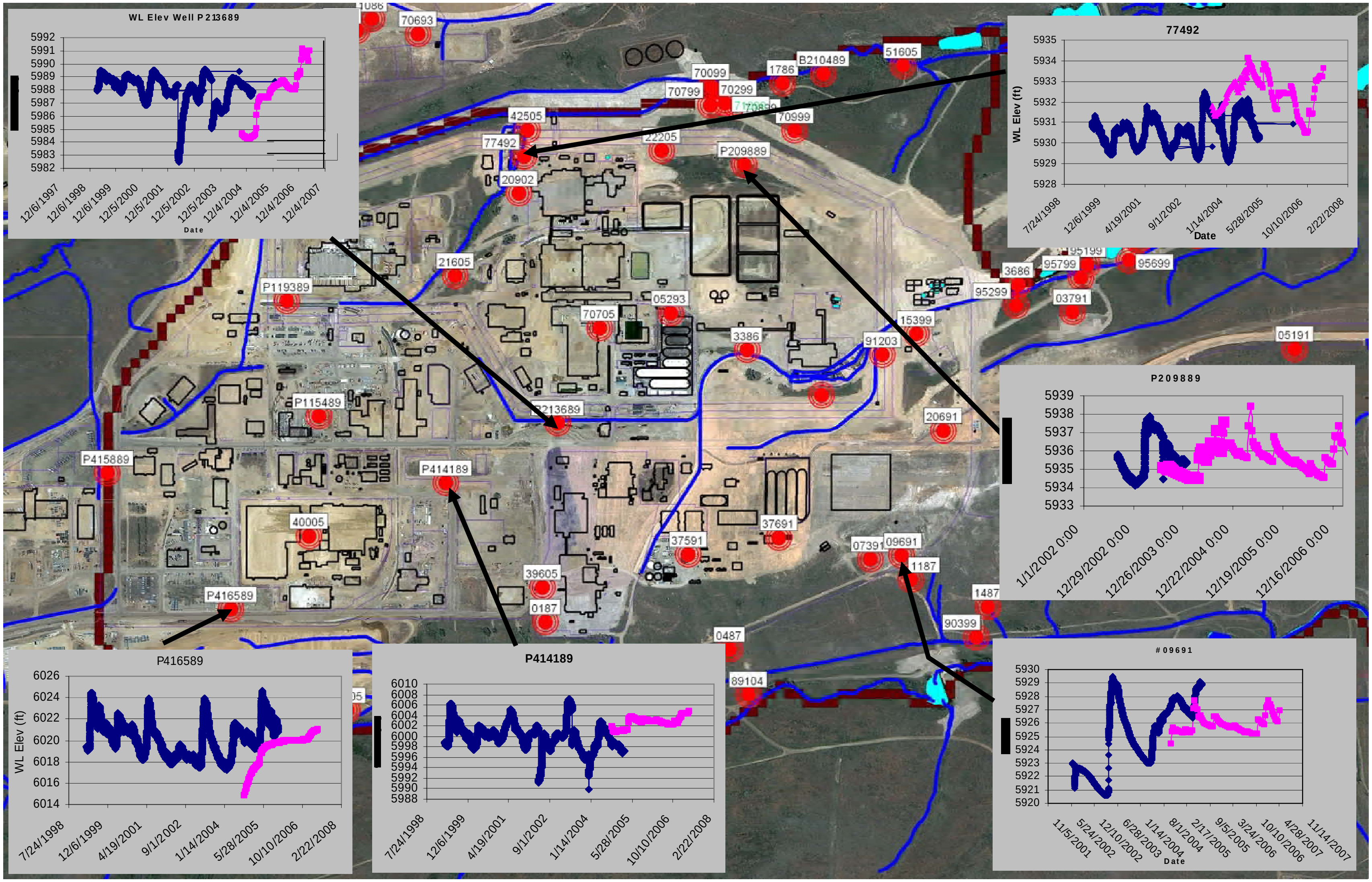


Figure 20. Simulated ground water elevations (pink) and observed continuously monitored ground water level data (blue) (feet amsl). Note: Most wells shown no longer exist, and of those shown with water level graphs, only well P416589 (upgradient OLF) remains.

simulation that alter local ground water flow paths significantly from average annual flow directions.

Therefore, it is reasonable to assume that long-term contaminant migration pathways are generally consistent with average annual post-closure flow directions previously estimated. This does not imply that short-term hydrologic perturbations to the ground water flow system caused by more extreme climatic events will not temporarily cause ground water flow directions to deviate from the estimated average annual flow directions. However, ground water levels recover to their respective seasonal cycles typically within months or shorter time periods. Post-closure simulations that were conducted produced ground water flow paths similar to the long-term flow paths determined in previous modeling described in the “Summary of Hydrologic Flow and Fate and Transport Modeling Conducted at the Rocky Flats Environmental Technology Site,” dated September 2005.

<u>Simulated Surface Water Conditions</u>

Simulated surface flow is compared to observed flow at gages GS10, SW018, and SW027 located within the IA VOC model boundary. Results for GS10 are shown on Figure 21. The estimated annual reduction in simulated post-closure surface flow at GS10 (37×10^6 to 0.9×10^6 gal/yr) is similar to the observed reduction (32×10^6 to 3×10^6 gal/yr) from water year 2000 (October 1999 to October 2000) to water year 2006. The updated model actually predicts a greater discharge at GS10 than the former post-closure model (0.9×10^6 gal/yr compared to the previously predicted 0.17×10^6 gal/yr). The updated model also reflects a similar reduction in the observed reduction in baseflow (from approximately 15 to 32 gpm during water year 2000 to approximately 3 to 8 gpm for water year 2006), although post-closure simulated baseflows were slightly lower, ranging from 1 to 3 gpm. Simulated daily flows do not capture the peaky, higher flow rates measured at GS10 as indicated on Figure 21. This is probably due to a number of factors, including use of NREL station rainfall data instead of local data, assuming fully established vegetation that would have increased ground water levels in the area, and specifying soil hydraulic properties that are more like undisturbed areas, rather than more likely compacted soils due to closure.

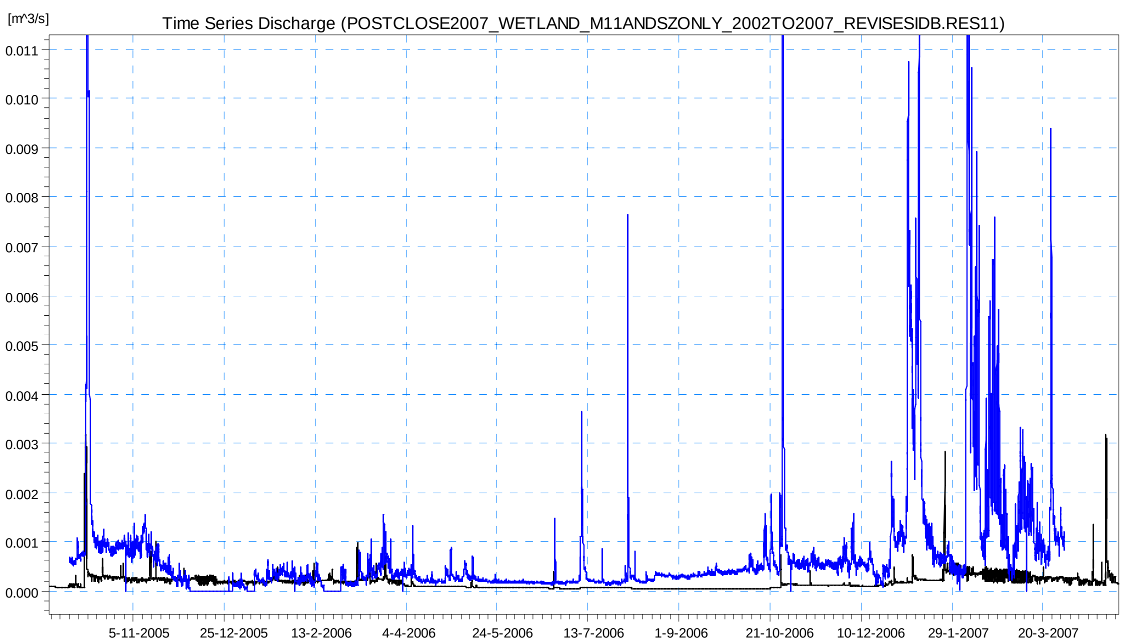


Figure 21. Simulated (black) and observed (blue) post-closure surface flow at GS10 (m^3/s). (Note that 1 m^3/s equals 15,837 gpm.)

Several reasons may explain the differences between simulated and observed flow at GS10, including the following:

- Former post-closure modeling assumed fully established vegetation. The current lack of fully established vegetation within the wetlands upstream and west of GS10 (as indicated on Figure 22) does not evapotranspire as much surface water as assumed by the model. Thus, the model underestimates flow at GS10.

Figure 22. FC-4 wetland area (May 14, 2007) from the slumping hillside. View is to the north.

- The NREL data, although from near the site, may not accurately reflect actual precipitation in the drainage basin flowing into GS10.
- Former and updated post-closure simulated flow at GS10 is very sensitive to the topographic surface configuration of the FC-4 wetland berms and routing of water through the drainage. The model assumes surface water fully fills each bermed area before flowing into the next area, based on designed berm heights. Based on field inspection (Figure 22), it is clear that the berms are not uniform in height and that berm features have been modified (variously notched and undercut). This would promote a greater throughflow of water to GS10 than originally assumed by the model, which would increase peaky flow responses at GS10.
- Surface soils within the drainage could have been compacted more than assumed for the Rocky Flats Alluvium fill material, leading to greater runoff.
- The post-closure seepage from the slumping hillside south of FC-4 (south of former Building 991) may be greater than was produced by the former French drain outfall (visually estimated prior to Site closure at 1 to 2 gpm).

Results of a comparison of (updated) simulated surface flow to observed flow at SW018 are presented on Figure 23. Only minor surface water discharge, as baseflow, is simulated at SW018 (approximately 0.3 gpm). Post-closure observed data are only intermittently available, but indicate both baseflow and direct runoff components. The baseflow appears to range from about 1.5 to 8 gpm. The model calculates some baseflow upgradient of this gage; however, it reinfiltrates, or lost to AET by the time it reaches SW018. Like at the GS10 gage, a combination of factors probably cause the model to under-estimate both the baseflow and direct runoff here, for example using NREL rainfall data, assuming fully established vegetation, and assuming no soil-compaction due to closure activities in the area, It is also possible that higher observed baseflow in this area may be caused by preferential drainage pathways from remnant subsurface utilities, utility corridors left in place, or corridors not fully disrupted near FC-2. The model does, however, simulate average annual heads reasonably well (Figure 18) in the area.

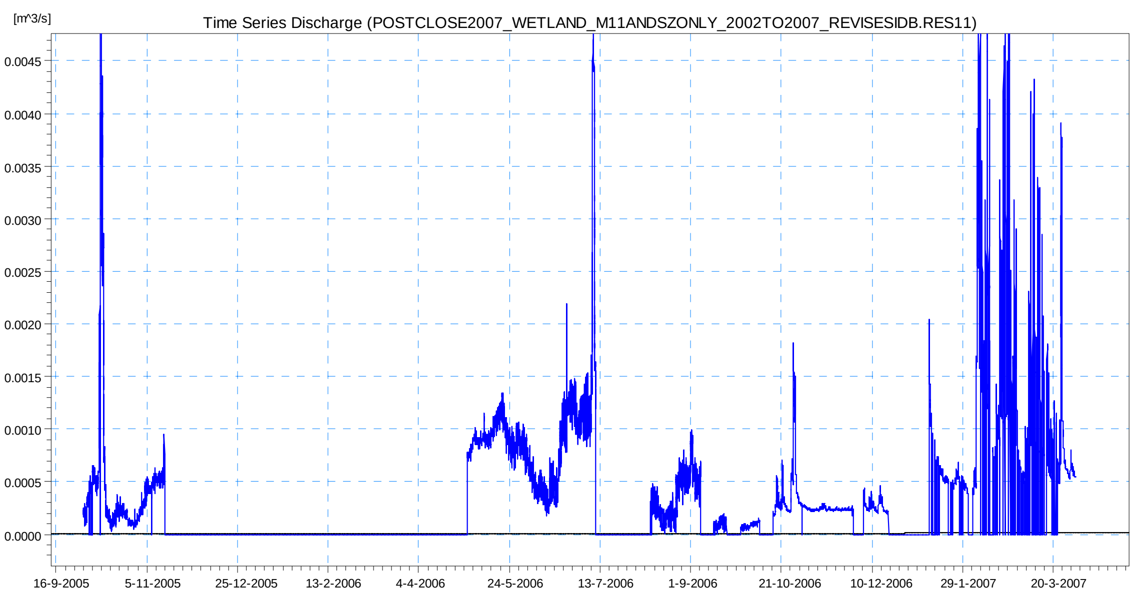


Figure 23. Simulated (black – approximately 0.3 gpm) and observed (blue) post-closure surface flow at SW018 (m^3/s). (Note that 1 m^3/s equals 15,837 gpm.)

The updated post-closure model produces approximately 1 x 10^6 gal/yr at SW027 (Figure 24), mostly as baseflow. The observed flow was zero for late 2005 through most of 2006; however, a sustained flow rate (above 50 gpm) was observed for most of February and March 2007. The model did not capture this dynamic. Pre-closure flows at this gage for water year 2000 were approximately 8 x 10^6 gal/yr, although most of this flow was due to inflow from drains tied to paved areas (e.g., the former Building 444 area).

Results of former modeling suggested that surface flows at SW027 are very sensitive to ground water levels along the entire length of the SID, with lateral inflows occurring along the entire length. Therefore, it is likely that simulated ground water levels are slightly higher than actual levels; this discrepancy generates enough simulated lateral inflow to produce the additional simulated flow at SW027. The sources of the significant amount of flow during February and March 2007 are uncertain, but given the long duration over which it was sustained and the heavy precipitation of the preceding months, it is clear the mechanism is related to discharge of rising ground water along the SID combined with short-term precipitation runoff mostly due to snowmelt.

Results of (updated) simulated discharge at the MSPTS, ETPTS, and SPPTS are compared to observed discharge on Figure 25. (A separate model was developed for the MSPTS area that more accurately represents the flow system, compared to the coarser-grid IA VOC flow model. Refer to the separate Mound report.) Despite this, the simulated volume of effluent discharge is similar to the mean daily observed discharge rates at each treatment system. Simulated discharges are shown with symbols that match the color of the observed discharges (curves without symbols). Simulated flows at the MSPTS and SPPTS reproduce the average observed flow rates, while the simulated ETPTS discharge is lower than observed discharges. In all cases, the simulated discharges do not adequately capture the short-term fluctuations in observed discharge rates. The most likely explanation is that the relatively coarse (60-foot) model grid does not capture localized features that control the near-trench flow dynamics.

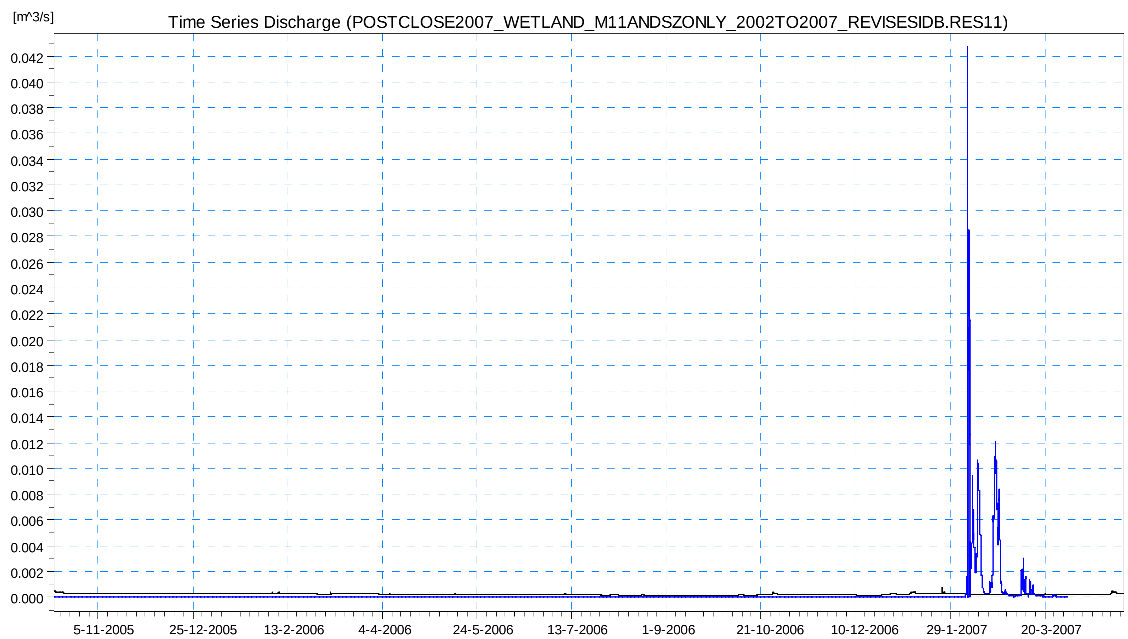


Figure 24. Simulated (black – nearly zero) and observed (blue) post-closure surface flow at SW027 (m^3/s). (Note that 1 m^3/s equals 15,837 gpm.)

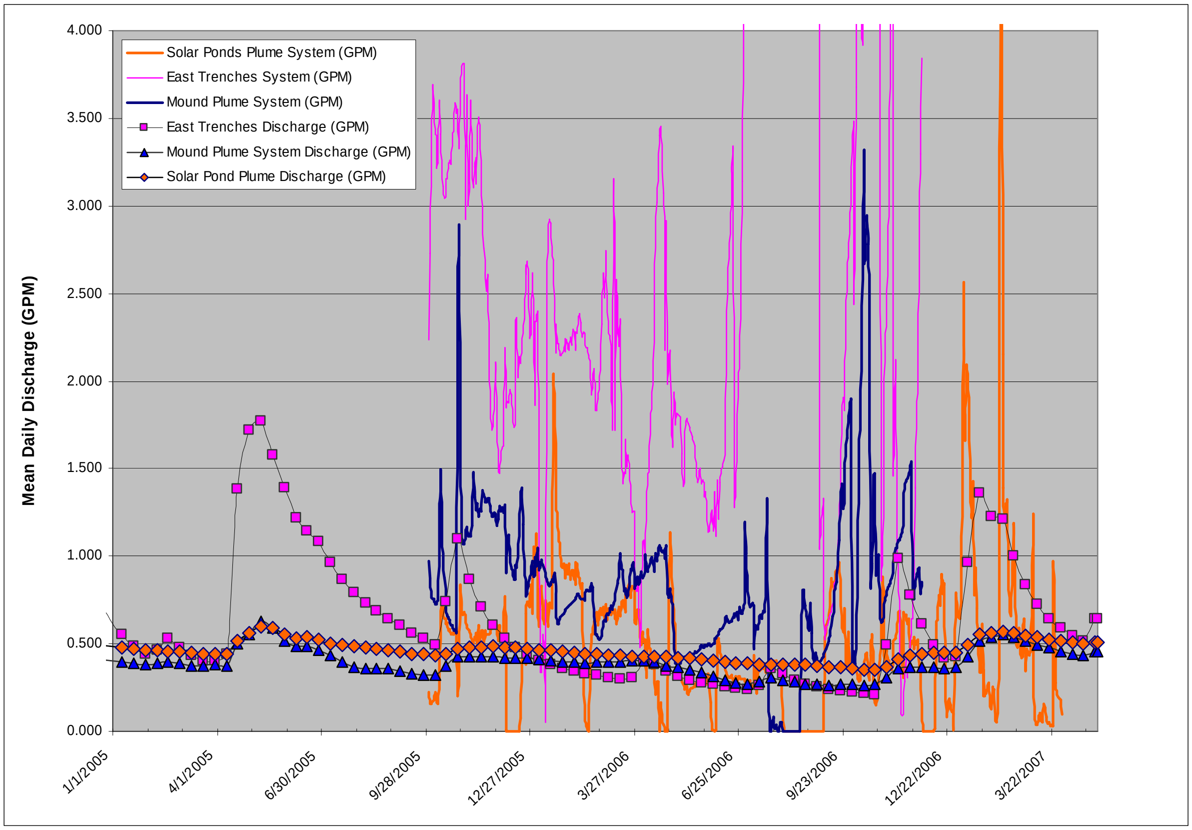


Figure 25. Simulated (lines with symbols) and observed (only lines – colored same as simulated with symbols) MSPTS, ETPTS, and SPPTS discharge (mean daily gpm). The flows shown for the ETPTS in June-August 2006 time period are not accurate; average flow over the period from May 15 through September 15, 2006, based on the instrument vault data rather than data from the manhole flume, was approximately 0.8 gpm.

6.0 Conclusions

Several conclusions can be made based on this work:

1) No major data gaps in post-closure hydrologic monitoring or VOC ground water monitoring were identified after reviewing the post-closure Site data, or through evaluation of updated model simulations.

2) The most recent post-closure surface topographic changes incorporated in the integrated IA VOC flow model showed only minor differences compared to the September 2005 planning version used in the former post-closure modeling. No major changes in ground water flow directions were identified due to the land surface topographic changes.

3) Post-closure VOC concentration data trends were not evaluated here. However, review of available post-closure hydrologic data, and comparison of previous and current post-closure modeling indicate that estimated ground water flow paths in plume areas have not changed significantly. In addition, discussions with Stoller also indicated that post-closure VOC concentrations do not deviate significantly from previously-mapped VOC distributions ("plumes") or pathways as of May 2007. The VOC fate and transport pathways in ground water are not expected to deviate significantly from former estimates derived through reactive transport modeling (K-H, 2004).

4) Simulated post-closure ground water levels compare well with the observed time-averaged levels within the IA VOC model boundary. The model simulates slightly higher than actual levels in wells screened in the unconsolidated material in the former Building 444 area, and in bedrock wells just north of the former Solar Ponds, though flow directions remain the same. Ground water flow directions, and hence contaminant transport pathways, are similar to former long-term simulated results.

5) Simulated post-closure surface water flows at gages GS10 (FC-4), SW018 (FC-2), and SW027 (eastern end of the SID) generally reflect the significant reduction in observed flows following closure. The model underestimates flows at all three locations. This is probably due to a combination of factors including partially established vegetation, differences between site climate data and the NREL site, higher surface discharge caused by remnant dust-suppression water used during decommissioning, and/or possible preferential pathways created by subsurface features or utility corridors left intact following closure. Detailed closure information and hydrologic/hydraulic information are insufficient to clearly identify the mechanisms leading to the differences between simulated and observed flow rates at these surface gages, as well as discharge from the treatment systems.

7.0 References

Kaiser-Hill Company, LLC, 2002, Site-Wide Water Balance Model Report for the Rocky Flats Environmental Technology Site, Golden, Colorado, May.

Kaiser-Hill Company, LLC, 2004, Final Fate and Transport Modeling of Volatile Organic Compounds at the Rocky Flats Environmental Technology Site, Golden, Colorado, April.

F.2 Report: *Mound Site Plume Treatment System Post-Closure (2007) Integrated Surface-Subsurface Hydrologic Flow System Assessment and Model Update, Rocky Flats Site*

January 28, 2008

MEMORANDUM

TO: John Boylan, S.M. Stoller

FROM: Bob Prucha, Integrated Hydro Systems, LLC

SUBJECT: Mound Site Plume Treatment System Post-Closure (2007) Integrated Surface-Subsurface Hydrologic Flow System Assessment and Model Update, Rocky Flats Site

This memorandum summarizes results of a post-closure integrated surface-subsurface hydrologic flow system assessment of the Mound Site Plume Treatment System (MSPTS) area. Available post-closure data have been evaluated and the former localized MSPTS integrated hydrologic flow model has been updated with new information since closure. The date of closure (U.S. Department of Energy [DOE] acceptance of contractor's declaration of completion) has been defined as December 8, 2005. Updated model results were assessed and compared to both previous post-closure simulations and actual hydrologic conditions in the area.

The scope of work was originally defined by S.M. Stoller (Stoller) (September 2005) and then modified to meet immediate needs in May and June 2007. This memorandum supplements the former Industrial Area (IA) post-closure hydrologic and hydraulic assessment summarized in a recent memorandum submitted to Stoller (dated July 2, 2007) entitled "Draft Post-Closure (2007) Integrated Surface-Subsurface Hydrologic & Hydraulic Flow System Assessment and Model Update."

Information in this memorandum is organized as follows:

1) Post-closure data evaluation;
2) Model updates and simulations; and
3) Conclusions.

1.0 Post-Closure Data Evaluation

Figure 1 shows the location of key features associated with the MSPTS area. To accurately represent the local-scale ground water capture zones associated with the MSPTS collection trench and associated French drain, a fully integrated hydrologic flow model was developed using a 10-foot by 10-foot grid. The increased grid resolution also allowed for improved simulation of local hydraulic effects around an additional trench that was created when a 72-inch storm drain pipe was removed during Site closure, and which was subsequently backfilled and tied into the MSPTS collection trench in approximately March 2005. Figure 1 shows the locations and features included in the integrated model domain of the MSPTS.

The model extent was defined so that inferred volatile organic compound (VOC) sources (i.e., Mound Site and Oil Burn Pit #2), current observations, and estimated contaminant distributions (plumes) could be modeled. Lateral boundary conditions are located far enough away from plume areas and do not influence flow or fate/transport calculations in these areas.

Key features affecting the local ground water response within the model area include the MSPTS ground water collection trench, the pre-existing French drain that connects to it at its western end, the corridor of backfill material associated with a former 72-inch storm drain pipe, and its gravel drain connection to the MSPTS trench. Other features within the model that may have affected the surface and subsurface hydrology include a temporary surface drainage ditch that conveyed water for up to several months in 2005 (yellow line in Figure 1), excavation areas associated with the Mound Plume Individual Hazardous Substance Site (IHSS) and the Oil Burn Pit #2 IHSS, the Arapahoe Sandstone (outlined in light blue lines in Figure 1) that subcrops the unconsolidated material, and the construction of Functional Channel (FC)-5 that merges with FC-4 from the south (located west of 72-inch drain).

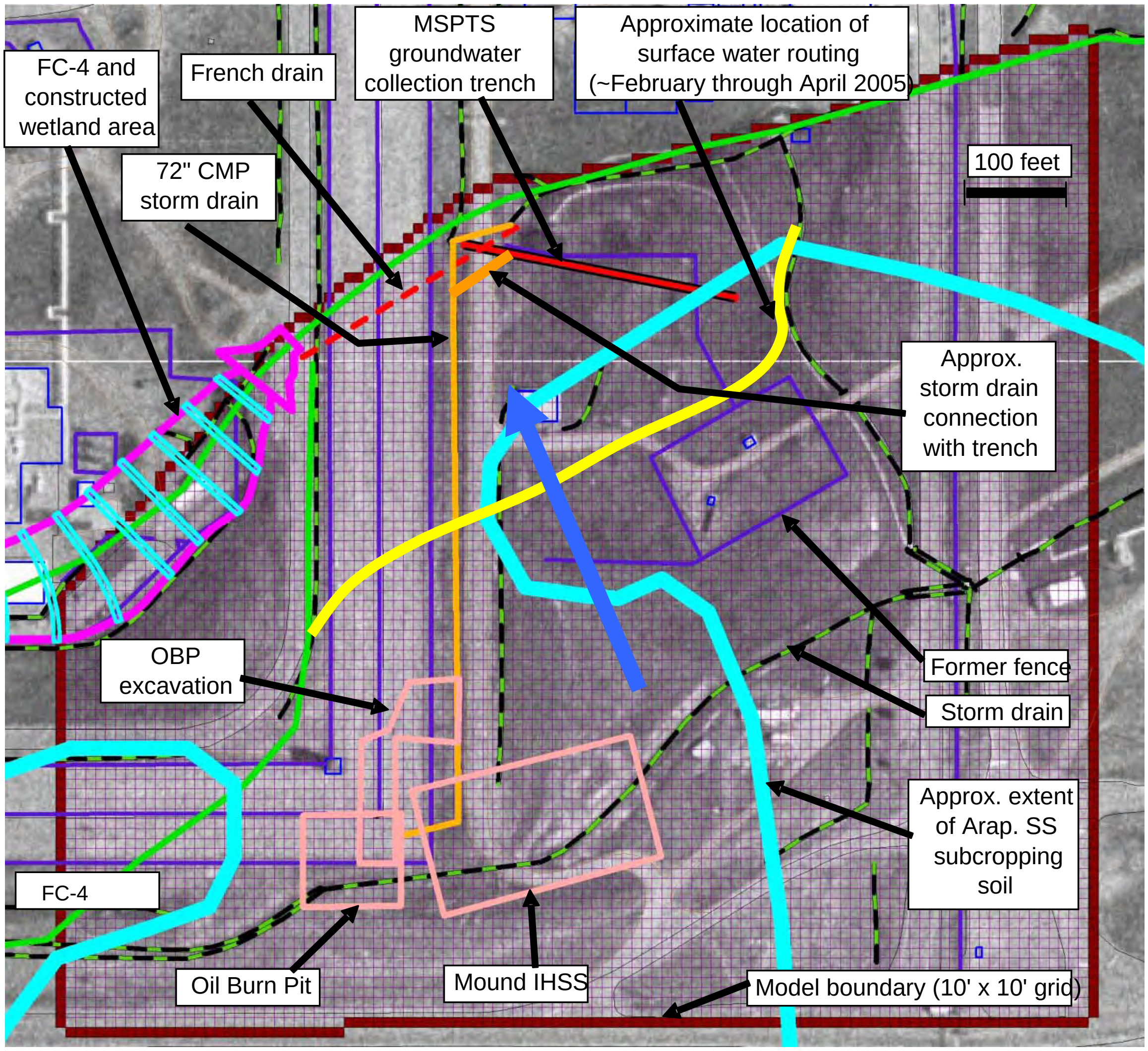


Figure 1. Integrated flow model boundary, grid, and Mound Plume area features. General groundwater flow direction is indicated by blue arrow.

Details and assumptions associated with the MSPTS area features are described below. Some of the feature detail within the model area are not well known and may affect the ability of the model to reproduce actual MSPTS discharge.

- Although the spatial location and length of the approximately 300-foot-long French drain were determined based on an older hard-copy diagram, no information was available on its depth or slope. It was assumed the drain was emplaced at the weathered bedrock surface within the unconsolidated material.
- The exact location of the gravel drain connecting the backfilled corridor from the former

72-inch storm drain to the MSPTS ground water collection trench was not available, although it is relatively close to that shown in Figure 1, based on available photographs. The approximate location and extent of the MSPTS ground water collection trench shown on Figure 1 are generalized, as this feature is not exactly linear.

- The depth of the backfill material in the corridor associated with the former 72-inch storm drain is not known. Based on its size and typical depths for other drains, the bottom depth was assumed to extend at least 10 feet below pre-closure grade. Greater depths were assigned to some areas of the corridor to maintain a relatively constant grade. No information was available on the saturated zone hydraulic properties of the storm drain backfill material, so this was varied as a calibration parameter.

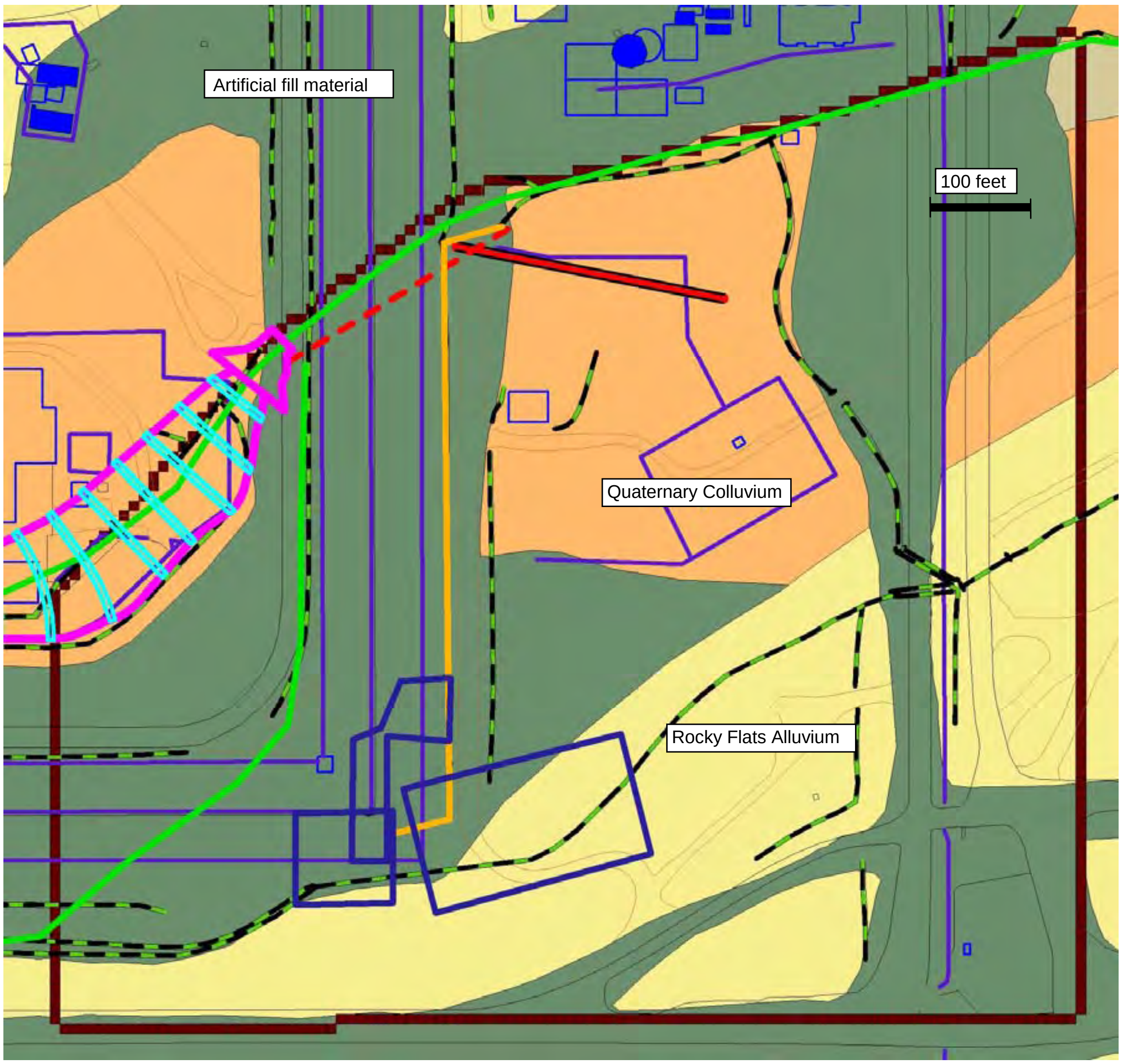


Figure 2. Pre-closure surface geology

- Hydraulic properties for the MSPTS ground water collection trench and French drain were not available. However, based on observations during construction of the system, very little flow was noted in the MSPTS trench, but when the French drain was intercepted, a substantial amount of flow was encountered. This may be due to higher saturated hydraulic conductivity values associated with the artificial fill material of the berm drained by the French drain, compared to the Quaternary Colluvium (Figure 2). As was done in the former Site-Wide Water Balance modeling, the surface geology (1995) shown on Figure 2 is assumed to represent the entire unconsolidated interval down to the weathered bedrock surface. This may not accurately reflect the screened-zone geology of wells monitoring ground water within the unconsolidated materials, especially in areas of artificial fill. However, artificial fill is generally composed of Rocky Flats Alluvium and their properties are very similar.

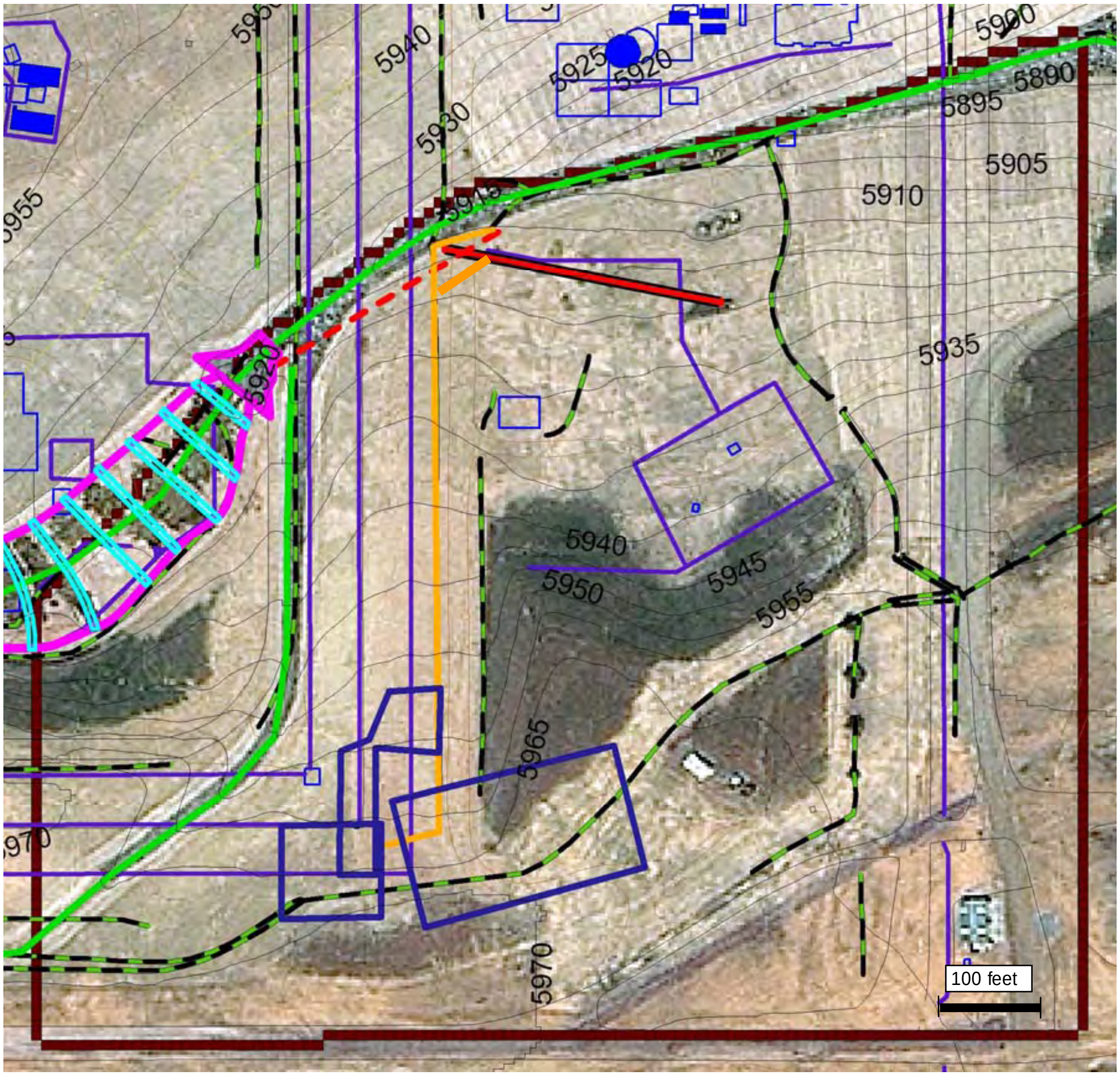


Figure 3. 2005 aerial photo of Mound Plume area. Darker shading indicates areas of dense vegetation (grasses).

- Vegetation coverage was signficantly altered, as indicated by the aerial photograph from 2005 shown on Figure 3. Most of the vegetation over the model area appears to have been regraded, although this took place over an extended period of time. The impact of this is an anticipated increase in the potential for ground water recharge over this area.

- Despite the regrading associated with closure, and excavations related to Oil Burn Pit #2 and the Mound Plume, the as-built post-closure topography (2007) differed very little compared to the former model input used in May 2005 (design topography). Changes were generally less than approximately 1 foot, and up to approximately 3 feet in some localized areas.

- The addition of many new boreholes and one new well in the Mound Plume area during 2005 provided additional geologic information on the weathered bedrock depth. This information was used to revise the former May 2005 top of weathered bedrock surface and is shown on Figure 4. Changes average less than 1 to 3 feet across the model area.

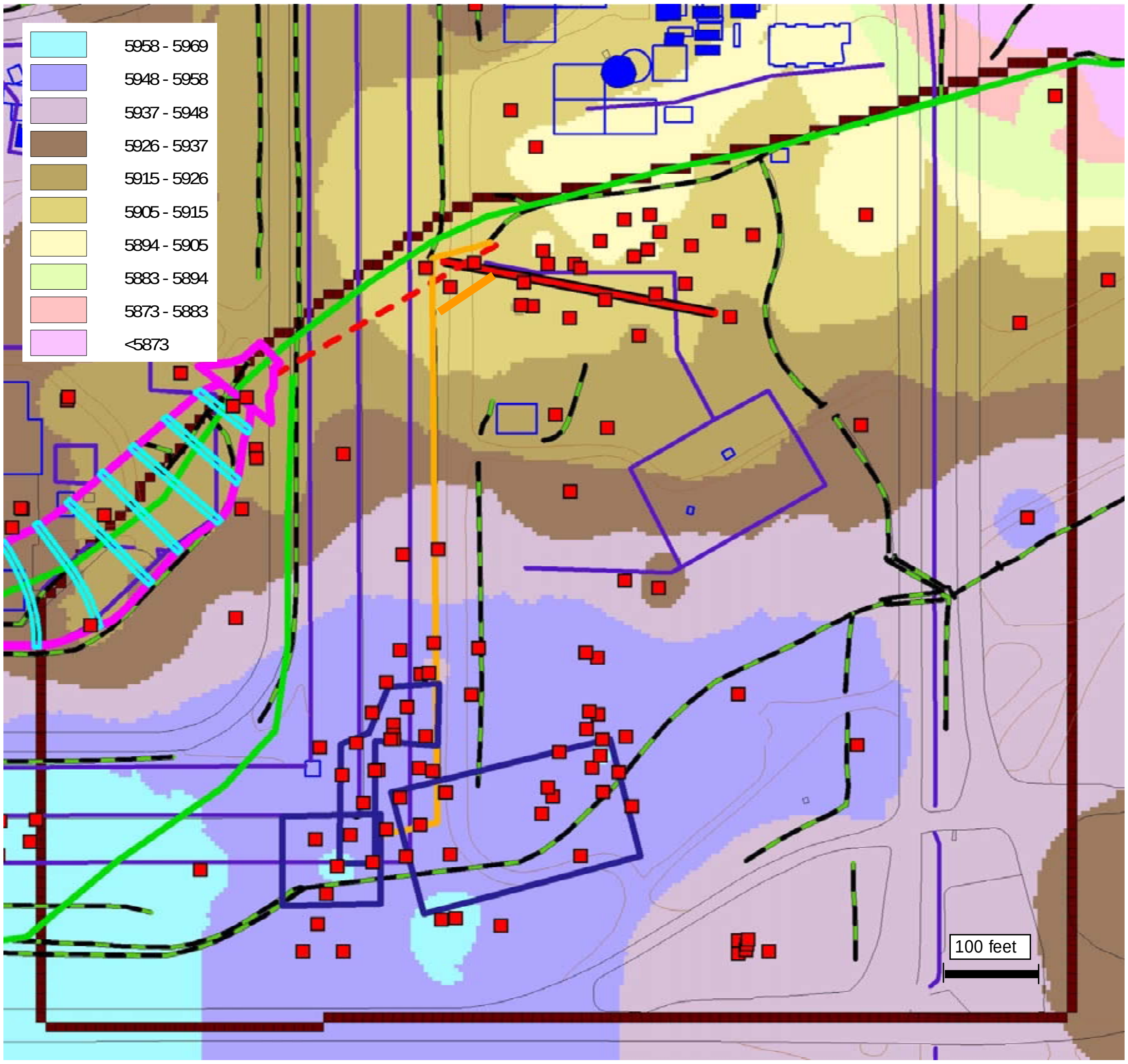


Figure 4. Revised top of weathered bedrock elevation (feet amsl) (control points shown as red squares). Legend indicates elevation in feet msl.

Post-Closure Hydrologic Observations

Several types of post-closure data were reviewed and compared to pre-closure conditions to assess the relative change to hydrologic conditions in the area. These include the following:

- Previous evaluation of site climate data indicated annual precipitation could be nearly twice as large in mesa areas to the north and west, compared to lower drainage areas within the former Rocky Flats Environmental Technology Site (RFETS), such as where the MSPTS is located. Despite this potential difference, the National Renewable Energy Laboratory (NREL) wind station climate data were used in this hydrologic evaluation and revised post-closure model simulations because they are more complete during periods of snow than the local data at unheated precipitation gage locations. A more detailed description of the NREL wind station climate data is presented in the IA VOC model update memorandum dated January 14, 2008.

- A saturated ground surface area, near the junction of what is believed to be the backfilled trench from the former 72-inch storm drain and the new gravel drain connecting it to the collection trench, was observed on a field visit during May 2007 (personal communication with John Boylan, Stoller). This suggests that the disruption of the backfilled corridor to the north of this junction, combined with possible higher, localized upgradient recharge rates related to excavations, and lack of vegetation may cause ground water levels to rise to near the ground surface at this location. No ground water wells or other subsurface data are available to confirm this is the case.
- Post-closure quarterly monitored ground water level data (average of quarterly measurements during 2006) show very little change has occurred compared to pre-closure data (average of ground water levels from October 1999 to October 2000), as shown on Figure 5. Although many pre-closure wells have been removed, data on Figure 5 suggest that in those wells that remain, ground water levels generally changed less than 3 feet. The exceptions to this are well 00897 (located upgradient of the MSPTS, near the Mound Site source area), where average ground water levels decreased approximately 4 feet, and several wells in the immediate area of the trench, where average ground water levels increased approximately 4 to 8.5 feet. The post-closure increase in ground water levels near the trench may suggest that ground water levels increased in a localized area just upgradient of the trench, possibly due to localized regrading, lack of vegetation, and climate variability; or may reflect the increased volume of ground water that has been routed to the trench since mid-2005. The pre- and post-closure monitoring over the area is not sufficiently detailed to support firm conclusions regarding the change in ground water levels.

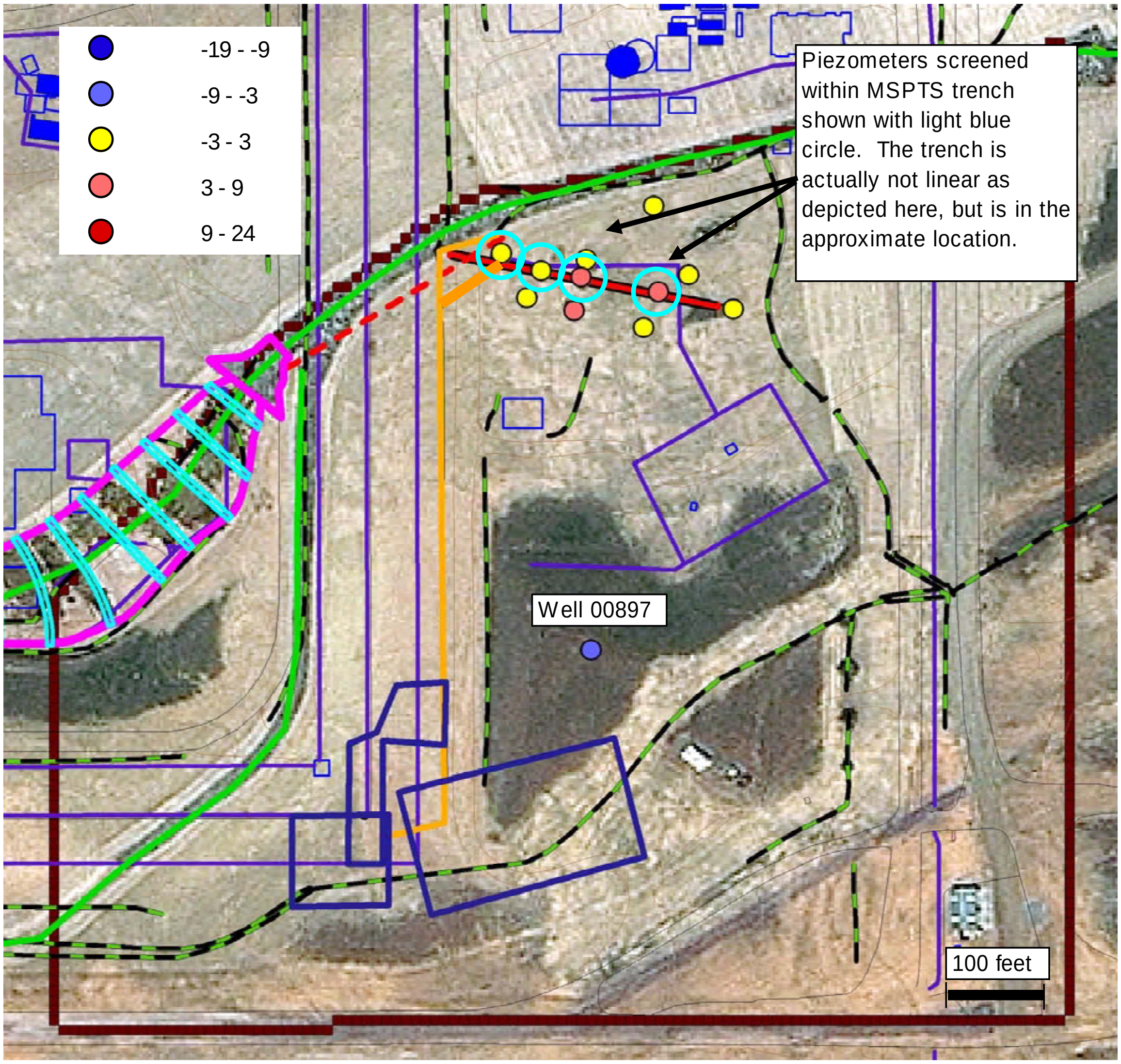


Figure 5. Comparison of average annual ground water monitoring well water levels (feet) (1999/2000 and 2006/2007). The legend shows the difference between simulated and observed levels (feet). Positive numbers (red) indicate water levels increased over the time period, and negative numbers indicate they decreased.

- Post-closure quarterly ground water level data also indicate only minor annual variability for 2006 as shown on Figure 6. Water levels vary less than 3 feet over the year, based on quarterly measurements, although they likely vary more in direct response to precipitation recharge events combined with drainage and evapotranspiration (ET) dynamics. Still, these data suggest that ground water levels over the Mound Site Plume area remained relatively stable throughout the year (2006).

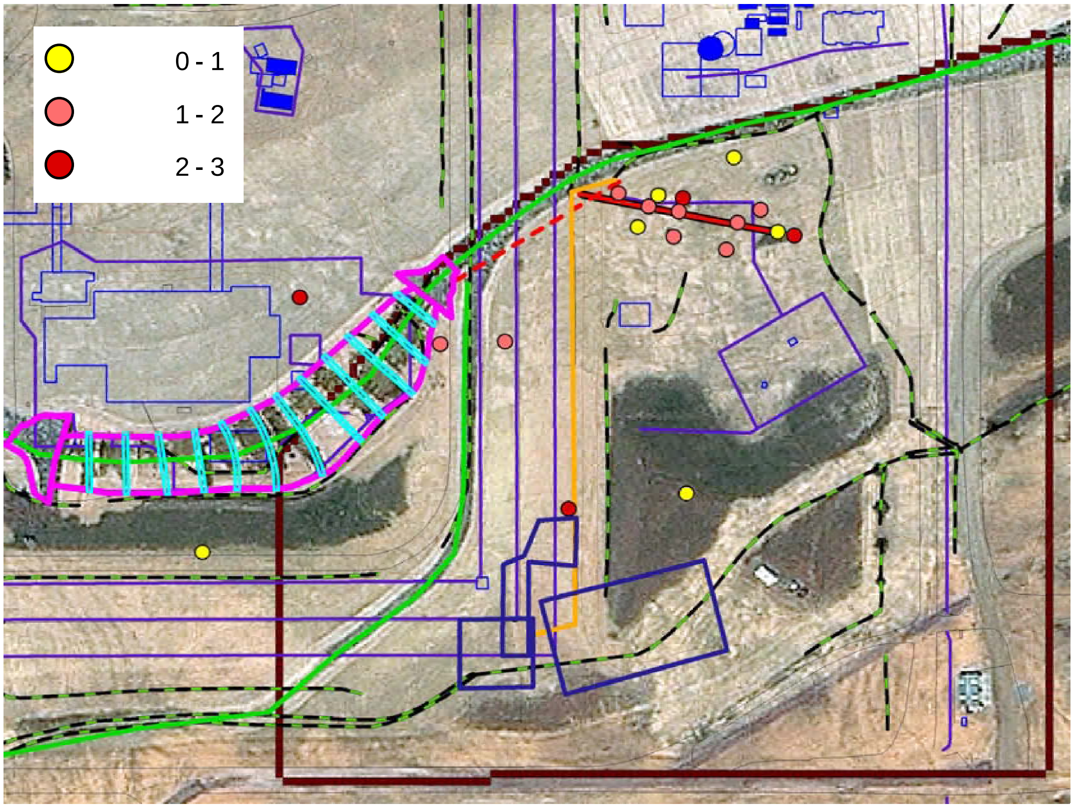


Figure 6. Observed post-closure (2006) variability in quarterly monitored ground water levels (feet) (mostly January, April, July, and October). The legend shows the magnitude of variability in feet.

- Continuously monitored (electronically logged at x-hour intervals??) ground water level data are available for only one well (well 91203) within the Mound Plume model boundary. These data are shown on Figure 7 and suggest ground water levels have declined in this location following closure, despite some obvious errors in the data (i.e., the abrupt changes in ground water levels at four different times). A comparison against quarterly measured data indicates the overall trend in continuously monitored data is consistent with the quarterly measurements. Two of the abrupt shifts coincide with quarterly measurements, when the transducer output is typically reset to physically measured ground water levels. This suggests these Troll dataloggers may have been reprogrammed on those occasions using incorrect reference elevations, and/or they may be experiencing drift problems typical of such transducer-based units.

  The transducer data indicate ground water levels declined from approximately March 2006 to March 2007. This occurred even during spring 2006 recharge events (typically March through May), which caused increased ground water levels in most other continuously monitored wells within the IA; and it also occurred over the higher-than-normal October 2006 through January 2007 period of precipitation (mostly snow). Therefore, this area appears to be dewatering since closure. This may be due to a combination of factors including:

  - Localized ground water drainage,
  - A lowering of ground water related to removal of the 72-inch storm sewer,
  - The tie-in of the backfill material corridor to the MSPTS ground water collection trench,

- o A possible increase of ET associated with installation of FC-5 nearby, which has yielded few surface flows to date, but where ground water levels are relatively shallow, and
- o The lack of infiltration from the former Central Avenue Ditch.

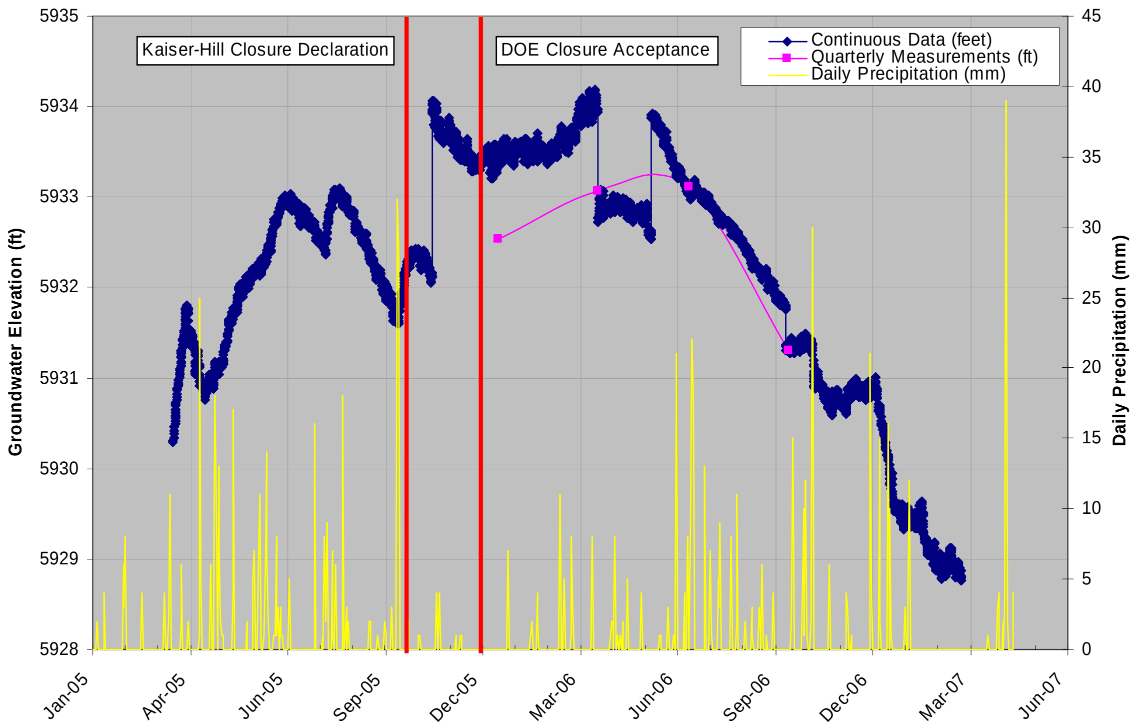


Figure 7. Observed pre- and post-closure ground water levels at continuously monitored well 91203. The red lines indicate respective closure dates.

- Estimated mean daily discharge in gallons per minute (gpm) from the MSPTS during the period January 2000 through March 2007 is shown on Figure 8. Red lines indicate the March 2005 and December 2005 dates when the storm drain was removed and the backfill material was connected to the MSPTS ground water collection trench, and DOE's acceptance of Site closure, respectively.

Several observations can be made about the discharge response from 2000 to 2007. The overall MSPTS discharge response is complex, but appears to be related to several factors, including intra-annual climate variability, land surface topography modifications, surface water routing across the area, and, perhaps most importantly, connection of the former 72-inch storm drain backfill material with the MSPTS ground water collection trench. These are described in more detail below.

- o The mean daily MSPTS discharge is quite variable over the entire period, ranging from approximately 0.1 to over 10 gpm. In most years, but more so before March 2005, average discharge drops to well below 0.5 gpm during late summer, when ET is highest and recharge is relatively low. Discharge rates increase abruptly, typically during spring time, when ground water recharge is highest and ground water levels increase in direct response to most large precipitation events. This is better illustrated on Figure 9, where daily precipitation data are compared against average daily MSPTS discharge rates. Most larger precipitation events clearly result in a relatively rapid response in the MSPTS discharge. Some events, for example the 30 millimeters per day (mm/day) (1.2 inches per day [in/day]) event during October 2006, do not affect discharge significantly, though this could also be due to differences in precipitation recorded at the NREL wind station compared to actual MSPTS conditions described above.

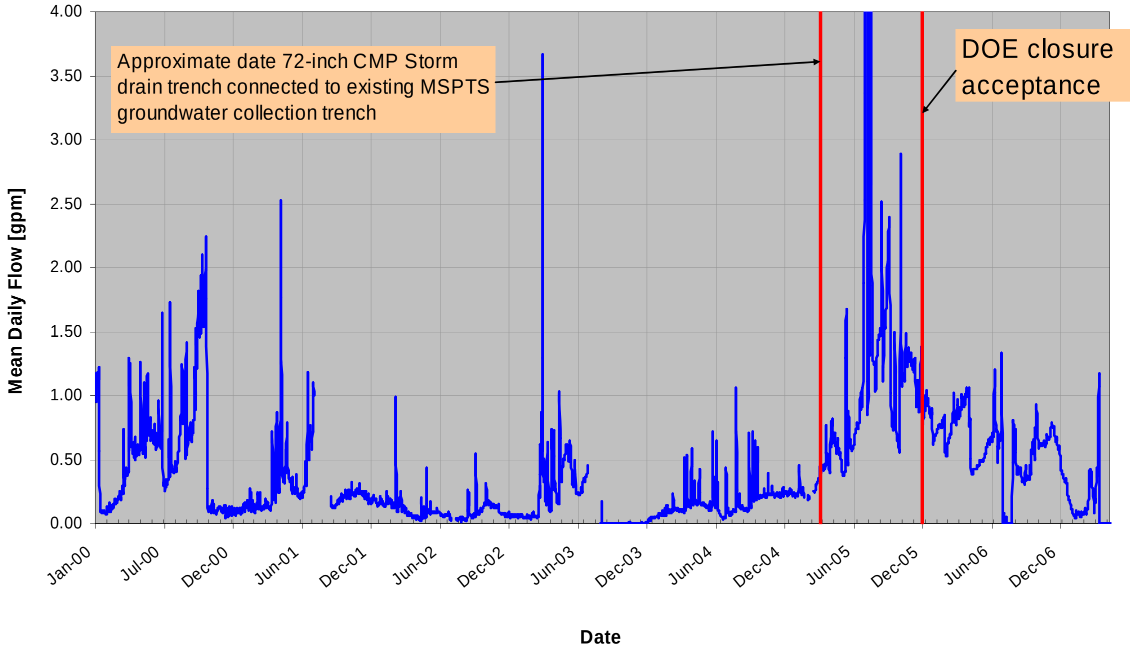


Figure 8. Measured pre- and post-closure (2000 to March 2007) MSPTS effluent discharge (gpm).

- o One interesting aspect of the MSPTS discharge response to precipitation is that the duration of this response is limited to 1 to 2 days. This response seems much faster than might be attributed to a ground water response based on review of continuous ground water level monitoring data throughout the former IA. Ground water response (i.e., ground water level increases) to precipitation typically takes weeks to months to show notable increases, and then decreases in response to drainage. The fast discharge response at the MSPTS suggests there may be a surface water connection, or localized areas adjacent to the MSPTS/French drain that exhibit very permeable soils (or possibly macropores) that are rapidly recharged, possibly due to localized interception of surface overland flow.
- o The MSPTS discharge increased significantly following connection of the former 72-inch storm drain backfill material to the MSPTS ground water collection trench (approximately March 2005). Average monthly discharge continued to increase from March to approximately October 2005, and then decreased erratically through January 2007. This response may be due to a decrease in the volume of ground water available within and adjacent to the backfill material associated with the 72-inch storm drain as it dewatered (personal communication with John Boylan, Stoller). The connection of the Oil Burn Pit #2 with the storm drain backfill, and the connection of this backfill material to the MSPTS, is substantiated by the notable increase in the VOC daughter product cis-1,2-dichloroethene detected in the MSPTS influent in April 2005. The increase is probably due to Hydrogen Release Compound™ (HRC) that was added to the Oil Burn Pit #2 source area backfill material. Other reasons for the significant increase in MSPTS discharge over this time period may be the following:
    - ▪ Routing of surface water through a temporarily unlined ditch crossing the former storm drain and immediately upgradient of the MSPTS ground

water collection trench (see Figure 1) from approximately February through April 2005 (or longer) likely caused localized surface water recharge of ground water through leakage. It is interesting that the increase in the MSPTS trench discharge took place over many months, peaking in approximately October 2005, approximately 7 months after connection to the storm drain backfill material. This is a relatively long period of time to see an increase in flow due to the connection. It also suggests the delay could be caused by the relatively slow ground water mounding in the area and subsequent flow through the artificial fill and Quaternary Colluvium to the MSPTS. The mounded ground water effects would have taken months to reach the trench, and cause MSPTS discharge to increase and decrease as observed on Figures 8 and 9.

- The lack of vegetation could locally increase recharge (i.e., through decreased ET) and thus ground water levels. The amount of pre- and post-closure ground water level data in the area is insufficient to confirm this occurred; however, it probably contributed to increased post-closure MSPTS discharge. As vegetation density increased following Site closure, recharge and ground water levels would show a corresponding decrease.
- Excavations in the area could have provided a more direct means by which ground water levels could have been recharged. Although this would have been localized, the increase in ground water levels could have resulted in increased ground water levels near the storm drain backfill material, French drain, and collection trench.

There is not sufficient continuously-monitored ground water level data from this area to confirm any of these hypotheses.

The overall response shown on Figure 9 suggests that the MSPTS discharge rate may eventually stabilize to a rate similar to that prior to connection of the storm drain backfill material to the MSPTS trench. This seems further supported by the low rates in February 2007 (less than 0.1 gpm), which are similar to those associated with the period prior to connection of the backfill material. In addition, the discharge rate during 2000 appears similar to that observed post-closure. This may further suggest that the several years preceding the storm drain backfill material connection in March 2005 produced lower-than-average ground water levels, and hence discharge.

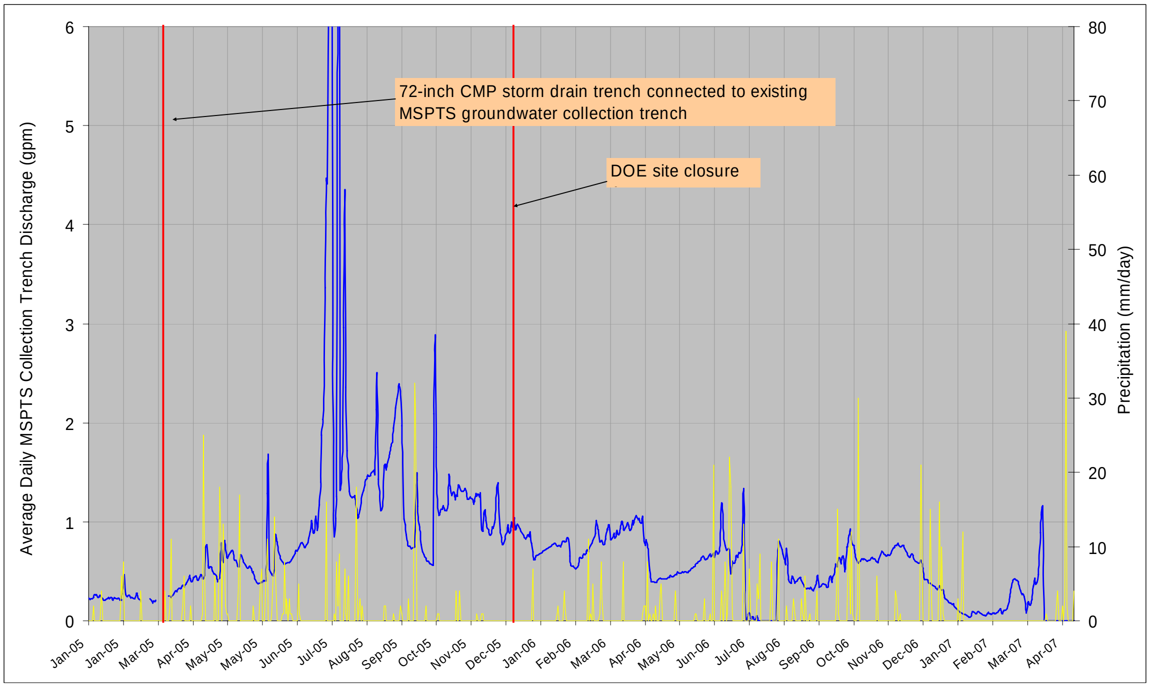


Figure 9. Comparison of MSPTS ground water collection trench discharge (gpm) shown with blue line to NREL station daily precipitation (mm/day) shown with vertical yellow lines.

2.0 Model Updates and Simulations

The localized MSPTS integrated flow model was originally established during March 2005, primarily to assess ground water flow paths in the vicinity of the Mound Site Plume and the approximate capture zone associated with the then-current configuration of the ground water collection trench. Recommendations based on this initial modeling work suggested that the permeable backfill material associated with a nearby 72-inch storm drain be physically connected to the existing MSPTS ground water collection trench to increase the potential capture of VOCs in the area. This was reported in the final Interim Measure/Interim Remedial Action document for ground water at RFETS by Kaiser-Hill (June 21, 2005). The MSPTS model was then updated again in May 2005 to reflect updates to the closure topography in the area. Simulated results showed ground water level and flow direction changes were negligible because the topographic change was minor in the Mound Site area.

Based on a review of available post-closure data and former modeling input and assumptions, the following data were revised and specified in the updated model:

- Surface topography;
- Bedrock surface;
- Former storm drain backfill material connection with the MSPTS ground water collection trench; and
- Climate data based on the NREL wind station climate data.

Initial updated model simulations were run for two separate time periods: one for pre-closure conditions from October 2003 to April 2005, and the other for post-closure conditions from April 1, 2005, to May 1, 2007. Two simulations were required because of the change in the surface topography and connection of the storm sewer backfill material to the existing MSPTS ground water collection trench from pre- to post-closure conditions. In reality, the change in surface topography did not happen instantaneously on April 1, 2005, but over a longer period of time, beginning before and ending after April 2005. Detailed records of the changes in surface topography were unavailable, but are generally considered to have a smaller impact on local hydrologic response compared to other factors.

Results of the initial updated model simulations indicate the following:

- Average annual simulated water levels at available post-closure quarterly monitored wells compare well with observed average annual ground water levels (2006) as shown on Figure 10. The quarterly monitored ground water levels do not reflect the relatively rapid seasonal ground water level fluctuations during the year, but do reflect reasonable average values that can be compared against average simulated annual ground water levels. The spatial distribution of current ground water level data in the area is not sufficient to capture the localized hydrologic response of key features, for example, along the former storm drain backfill material, French drain, or MSPTS ground water collection trench.

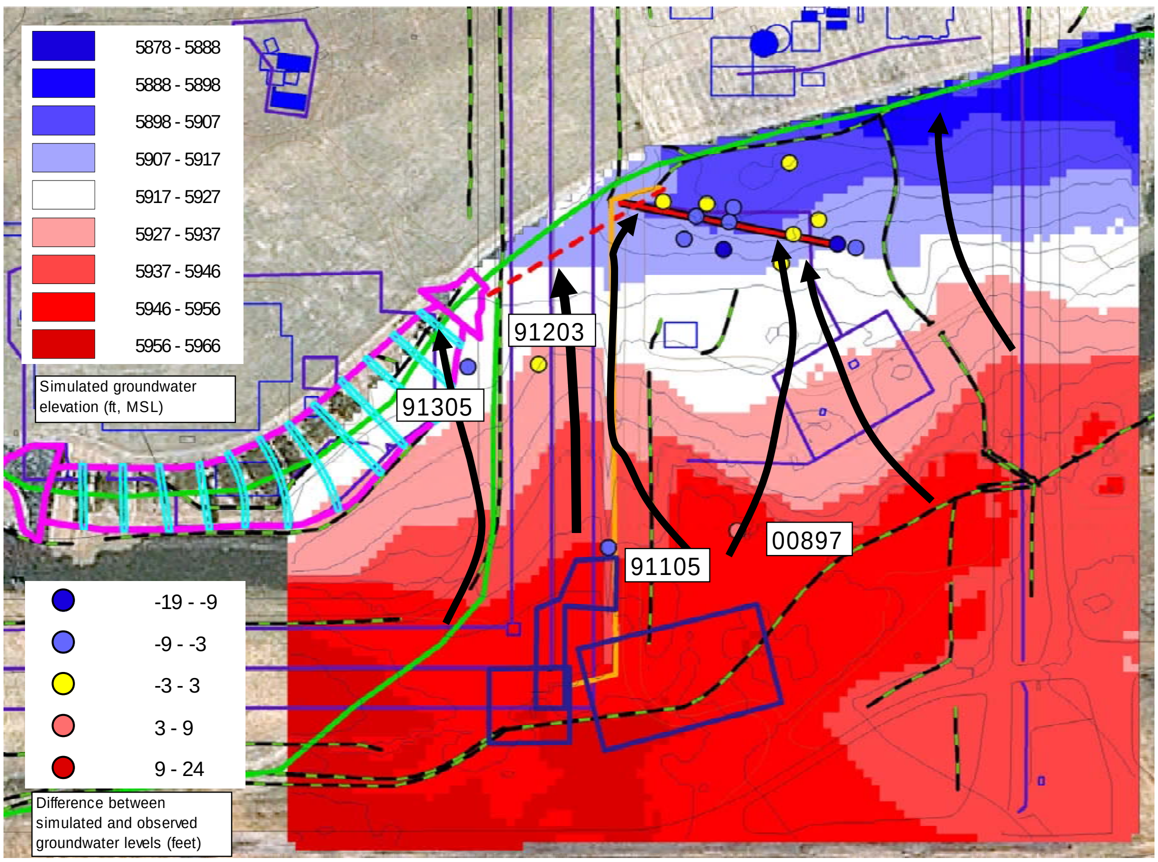


Figure 10. Difference in average annual simulated and observed (2006) ground water levels (feet) shown with color-coded circles (lower legend). Simulated ground water elevations are shown in color gradients (upper legend). Black arrows indicate approximate ground water flow paths.

In upgradient wells, it is clear that the model undersimulates (underestimates) ground water levels at wells 91305 and 91105, but oversimulates (overestimates) ground water levels at well 00897 (by approximately 9 feet). Well 00897 is located just east of 91105, near the Mound Site source area. At well 91105, located very close to the former 72-inch storm drain (shown as an orange line on Figure 10), simulated ground water levels are too low (-3 to -9 feet), suggesting simulated discharge to this former drain backfill material may be too high. Ground water flow directions indicate most ground water immediately south of the French drain/MSPTS ground water collection trench is likely intercepted by this system. Ground water flow at well 91305 does not appear to be intercepted, consistent with pre-closure predictions.

- Simulated MSPTS discharge using a drain constant of 1.0 x 10^{-6} 1/s for both the French drain and trench, and a hydraulic conductivity value of 0.0001 meter per second (m/s) for the storm drain backfill material, produced approximately 1 to 2 gpm of flow from 2002 through 2007. Although this is similar in magnitude to the observed average annual discharge rate from the system, it does not reflect the observed short-term, peaky discharge response well. This short-term response is directly related to larger storm events throughout each year. In addition, it does not capture the lower discharge rate prior to the connection of the storm drain backfill material with the MSPTS trench as shown on Figure 11. Simulated discharge does respond to changes in climate that roughly correlate with observed data; however, the timing of specific peak discharges do not correlate well. This is likely due in large part to differences between climate at the NREL wind station (approximately 2 miles away) and at the MSPTS area. It could also be due to localized surface infiltration as well.

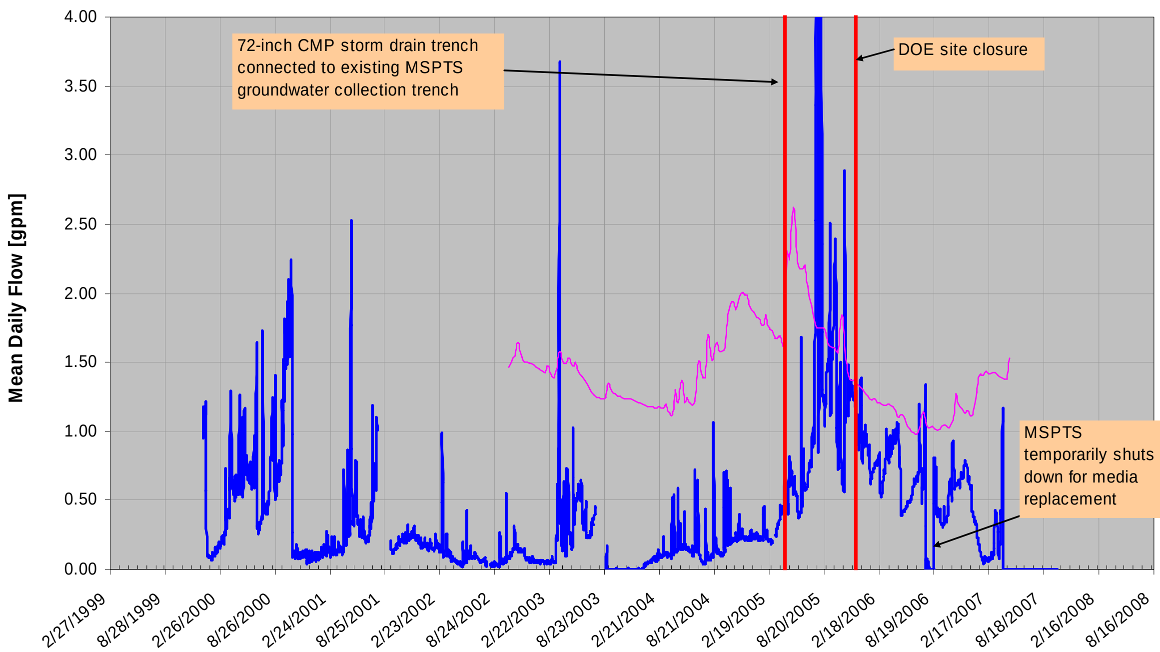


Figure 11. Observed and simulated discharge from the MSPTS (gpm). The dark blue line is observed discharge, while the magenta line is simulated discharge. The vertical red lines indicate the storm drain connection date and site closure date.

Based on the initial simulations, several modifications were made to assess the sensitivity of simulated pre- and post-closure discharge rates and annual ground water levels throughout the year to varying model inputs. Specific modifications included the following:

- Hydraulic conductivity values for the artificial fill and former storm drain backfill material were increased to promote larger and faster lateral inflows to the storm drain backfill material corridor, which in turn would provide increased inflow to the MSPTS.

- Drain constants along the French drain and MSPTS ground water collection trench were initially decreased to reduce overall discharge from the MSPTS. In subsequent simulations they were also spatially varied to be more consistent with observations during initial construction. Most of the initial MSPTS trench flow came after connection with the French drain (approximately 2 gpm).
- Input to the model vegetation database was adjusted to reflect the low post-closure coverage density.
- Localized ground water mounding in response to temporary surface water routing from the 700 Area from February through April 2005 was simulated to be approximately concurrent with the connection of the storm drain backfill material to the MSPTS ground water collection trench.
- Hydraulic conductivity values for the weathered bedrock were decreased (Arapahoe Sandstone was assumed to be equivalent to the claystone bedrock material). Specifying lower values may cause the MSPTS to be more effective at capturing shallow ground water flow that might otherwise bypass it in the weathered bedrock.

Results of these sensitivity simulations indicated the following:

- Adjusting the hydraulic conductivity values of the artificial fill material and storm drain backfill material had only minor effects on the simulated response on the MSPTS discharge. Neither the magnitude nor the short-term fluctuations (i.e., peaky response) changed significantly. Higher values caused uphill shallow ground water levels to drop slightly, and near-MSPTS levels to increase slightly as expected.
- Decreasing drain constants in the French drain and MSPTS trench had a direct effect on decreasing the MSPTS discharge magnitude, but had no effect on the short-term fluctuations. The peaky response in observed discharge could not be accurately reproduced. In addition, the notable increase in post-closure (storm drain backfill material connected to MSPTS) discharge was not simulated.
- Lowering the hydraulic conductivity of the Arapahoe Sandstone had only limited effects on the MSPTS discharge. The model oversimulated ground water levels in uphill (upgradient) wells from the MSPTS (i.e., well 00897). Lower hydraulic conductivity values reduced the uphill drainage of shallow ground water through the Arapahoe Sandstone.
- Simulating reduced vegetation for post-closure conditions did cause the MSPTS discharge to increase, but only by approximately a factor of 1.5 (see Figure 12).
- Simulating ground water recharge caused by the temporary surface water routing from the 700 Area along with reduced vegetation also caused an increase in MSPTS discharge as shown on Figure 12. However, the simulated increase in discharge (approximately twice) is much lower than that observed (about 10-fold).

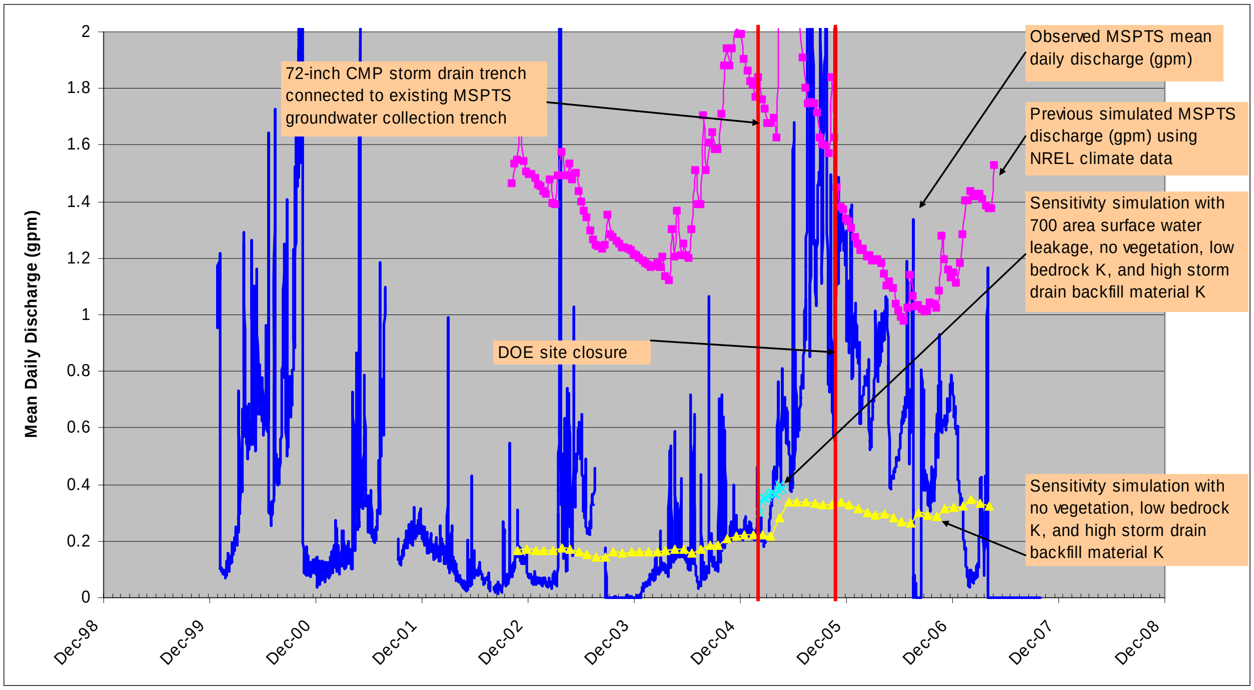


Figure 12. Simulated versus observed MSPTS ground water discharge (mean daily gpm) (K represents hydraulic conductivity).

3.0 Conclusions

Review of post-closure data suggests that ground water levels in the vicinity of the MSPTS have not changed significantly since closure in late 2005. However, the volume of MSPTS discharge increased significantly following closure. The lack of a similar observed response in ground water levels measured in the post-closure ground water monitoring well network suggests that the increased MSPTS discharge may be localized, and may even be somehow reflecting the faster-responding stage height in FC-4, or even FC-5 surface flow. In other words, the increased discharge may be due to a local mechanism that is simply not captured by the post-closure monitoring wells.

Review of the previous MSPTS model used to simulate post-closure conditions indicated that it reproduced observed post-closure ground water levels well. However, this model did not reproduce the significant increase in MSPTS discharge rates following connection of the former 72-inch storm drain backfill material with the MSPTS trench after March 2005. This model also did not simulate the peaky discharge response of the MSPTS, which clearly responds to many precipitation events throughout the year. As a result, several sensitivity simulations were made to this model's input to assess which factors affect simulated MSPTS discharge, while continuing to reproduce observed average annual ground water levels in the MSPTS vicinity.

Based on the sensitivity analyses, several conclusions can be made:

1) The peaky response of the MSPTS ground water discharge is difficult to reproduce in the model. Two likely reasons for the peaky response are:

    a. The MSPTS is connected to surface water (i.e., the French drain could have been intercepted by FC-5 or FC-4).

    b. The soils adjacent to the MSPTS are much more permeable than assumed in the model. Both the pre- and post-closure discharge response is peaky.

2) The source of the VOCs detected in well 91305 remains uncertain. It is possible that flows from this source area are not captured by the MSPTS (including the French drain).
3) The former 72-inch storm drain backfill material corridor likely acts as a preferential conduit for ground water flow to the MSPTS. However, model simulations indicate the areal extent over which ground water is captured is likely small because of the limited extent of permeable backfill material, and because much of this material is surrounded by lower permeability weathered bedrock material.
4) Results of modeling suggest that the significant increase in MSPTS discharge following the March 2005 time frame is likely due to a combination of factors including:
    a. Connection with the former storm drain backfill material;
    b. Regrading and lack of vegetation coverage in the area; and
    c. Routing of 700 Area surface water immediately upgradient of the MSPTS from west to east.

F.3 Report: *Original Landfill Post-Closure (2007) Integrated Surface-Subsurface Hydrologic Flow System Assessment and Model Update, Rocky Flats Site*

January 28, 2008

MEMORANDUM

TO: John Boylan, S.M. Stoller Corporation

FROM: Bob Prucha, Integrated Hydro Systems, LLC

SUBJECT: Original Landfill Post-Closure (2007) Integrated Surface-Subsurface Hydrologic Flow System Assessment and Model Update, Rocky Flats Site

This memorandum summarizes the results of a post-closure integrated surface-subsurface hydrologic flow system assessment for the Original Landfill (OLF) area at the Rocky Flats Site. Specifically, post-closure observed data have been evaluated and the former OLF integrated hydrologic flow model (Kaiser-Hill, 2005) has been updated with new information since closure of the Rocky Flats Site. The date of closure (U.S. Department of Energy [DOE] acceptance of contractor's declaration of completion) has been defined as December 7, 2005. Updated model results were assessed and compared to both previous post-closure simulations and actual observed hydrologic conditions in the area. Although simulations show a good correlation with observed conditions, some revisions were made to the model to improve the correlation. For example, with the revised post-closure model, a shallow subsurface drain was simulated in one seep area to evaluate the hydrologic impact of the proposed routing of surface discharge away from this area.

The scope of work was originally defined by S.M. Stoller Corporation (Stoller) in September 2005 and then modified to meet immediate needs in April and May 2007. This memorandum supplements the former Industrial Area (IA)-wide post-closure hydrologic and hydraulic assessment summarized in a recent memorandum submitted to Stoller on January 28, 2008, entitled "Industrial Area Post-Closure (2007) Integrated Surface-Subsurface Hydrologic and Hydraulic Flow System Assessment and Model Update."

Information in this memorandum is organized as follows:

1) Post-closure observed data evaluation;
2) Model updates and simulations; and
3) Conclusions.

1.0 Post-Closure Observed Data Evaluation

Figure 1 shows the location of key features associated with the OLF as follows:

- Approximate extent of the landfill waste;
- Boreholes with geologic information;
- Ground water wells;
- Surface drainage features including Woman Creek to the south (blue line) and surface channels created by berms extending to the western and eastern sides of the OLF; and
- Clay toe buttress.

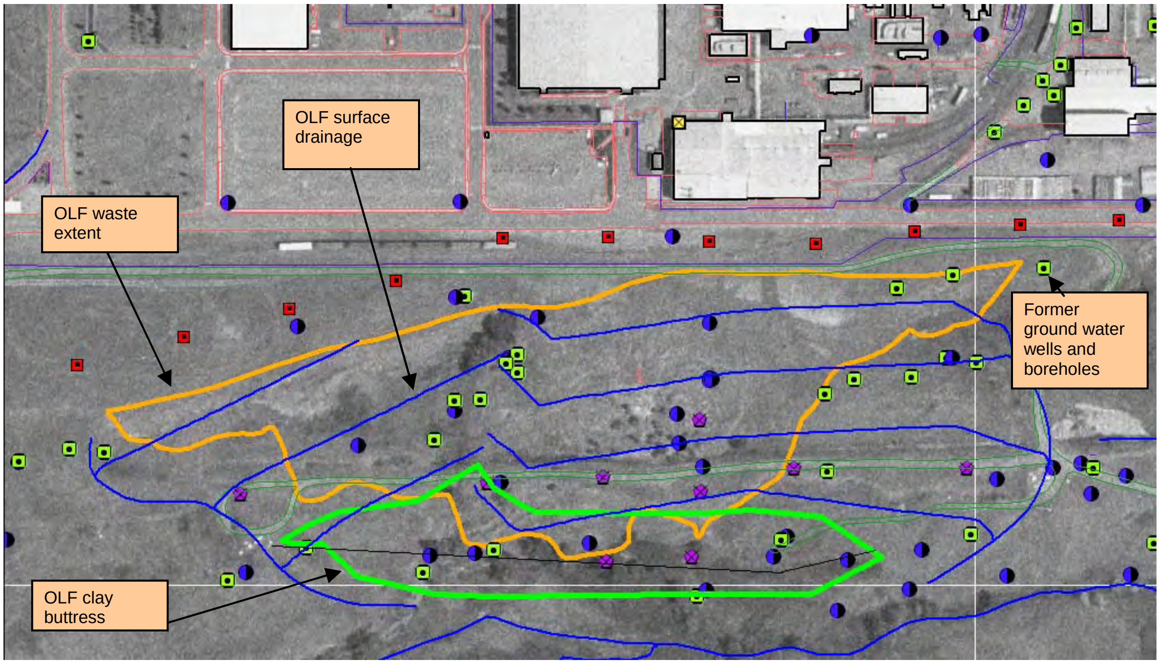


Figure 1. OLF features. Red squares represent recent boreholes drilled in support of the landfill closure design. All other symbols are former boreholes in the area. Photo background represents conditions prior to Site closure.

Figure 2 shows pre-existing seep areas in the OLF area, along with current seeps as of May 2007. Some of the recent seeps are likely related to former seep areas, such as Seep #7, located just above the clay buttress and below the former larger seep area located approximately 100 feet uphill to the north. Several photos were taken of the Seep #7 area as shown on Figures 3 and 4. During a visit to the OLF in May 2007, Seep #7 flow rates appeared to be approximately 5 to 10 gallons per minute (gpm) based on visual inspection. A current seep complex at the northeastern corner of the landfill, along the surface drainage berm, sits just downhill (south) of another former seep complex.

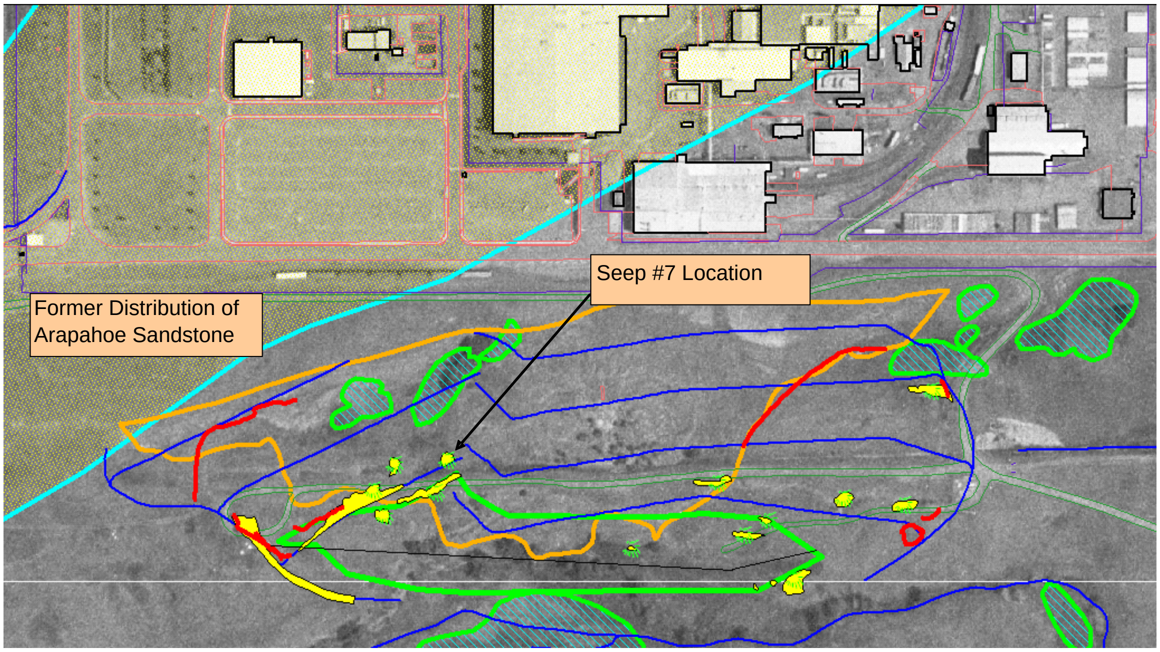


Figure 2. Mapped seep locations. Former seep locations (pre-closure, from seep mapping efforts in the mid-1990s) are shown in green, and post-closure (spring 2007) seep locations are shown in yellow with a green boundary. Slump locations mapped in early 2007 are shown with red lines. Upper-left portion of figure with different shading marks approximate edge of Arapahoe Sandstone discussed later. Photo base is from pre-closure era.

Figure 3. Seep #7 area. Seep surface discharge is over an approximately 20-foot x 20-foot area (May 2007).

Figure 4. Surface runoff from Seep #7 into the western side channel (OLF diversion Berm #3). Picture is taken from the west drainage channel looking east along the Berm #3 channel toward Seep #7, which is located approximately 430 feet away.

Despite the apparent correlations between current and former seep locations, several new seep areas appear to have developed for a combination of reasons:

- The OLF area vegetation coverage density is only approximately 20 percent established. This sparse vegetation effectively promotes infiltration and recharge of local ground water that would otherwise have been intercepted or transpired to the atmosphere by fully established vegetation.
- Perhaps the single most important factor determining seep formation is the depth to the weathered bedrock, or the thickness of the unconsolidated material. Figure 5 compares the locations of recent seeps to a map of the depth to the weathered bedrock. This surface was created by subtracting the current surface topography, with the more recent side channels and surface berms, from a carefully estimated (interpolated) weathered bedrock surface constructed using geologic borehole information available as of March 2005. More recent seep locations not explained by former seep locations correlate well with areas where weathered bedrock is relatively shallow. These shallow bedrock areas are generally adjacent to thicker unconsolidated materials which provide a source of ground water that is forced to discharge where the unconsolidated material starts to thin. This situation is most evident along the lower (southernmost) portions of the side channels where, as shown on Figure 5, the weathered bedrock is nearly at the ground surface. The much lower permeability of the weathered bedrock compared to the unconsolidated material forces ground water to the surface in these areas.

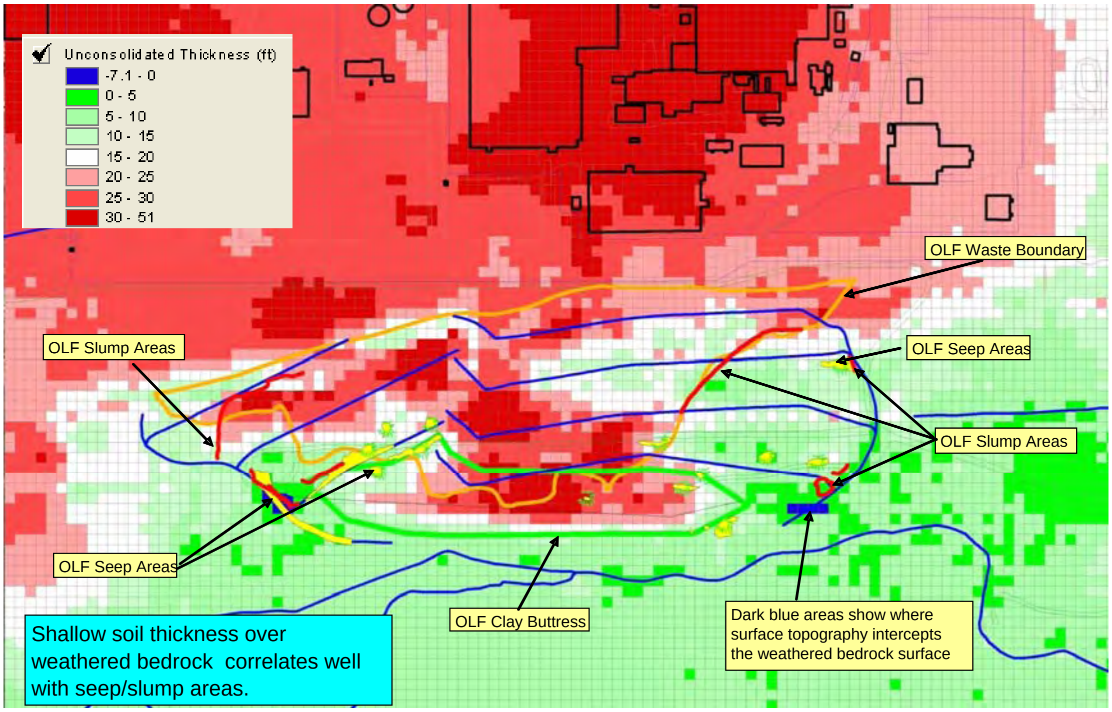


Figure 5. Updated post-closure depth to weathered bedrock, or thickness of unconsolidated material (feet), using the post-closure surface topography from the June 2006 flyover.

- Snow accumulation during December 2006 through February 2007 along and downhill of berms, and subsequent melting, could have caused significant localized ground water recharge in some areas. Because most surface flow in the OLF bermed channels is reported to have occurred during snowmelt, additional focused recharge along these channels or at their interception with the side channels may have also led to increased ground water saturation at the ground surface. This may be especially true for another continuously flowing seep observed May 14, 2007, located just below the eastern end of the clay buttress and estimated to discharge between 5 and 10 gpm. The fact that this still flows, and Seep #7 doesn't by the end of summer 2007, suggests it probably drains a larger uphill area impacted than Seep #7.
- Higher precipitation from late 2006 to approximately April 2007 is likely the cause of increased seep discharge and number of seeps.
- Some of the seeps may be related to the lower permeability of the clay buttress, which may cause perched ground water conditions above (i.e., the westernmost end of the buttress may reflect these conditions).
- Seeps along the central and western portion of the northern edge of the clay buttress seem most related to Seep #7, which discharges mainly from the central area and then flows down the local bermed channel (Diversion Ditch #3) to the western side channel. The area where Berm #3 meets the western channel has also been subject to slumping, and coincides with an area of former seeps (as per John Boylan, Stoller). Seep #7 appears to have been flowing for some time, and the water does not infiltrate into the fill material and the gravel drain installed on the upgradient side of the clay buttress to address flow from this seep. This suggests that the Seep #7 gravel drain, and/or the

engineered gravel drain beneath the buttress, may not effectively drain ground water upgradient of the buttress into the alluvium along Woman Creek. No monitoring data exist to verify this condition; however, ground water flow beneath the clay buttress through the gravel is limited, not by the high permeability of the gravel, but by the relatively lower permeability of the alluvium where the gravel terminates. The intent of this gravel drain was to drain any ground water that might otherwise build up behind the buttress through the alluvium. However, flow within the gravel drain could be impeded by either the relatively low alluvium permeability, or possibly by reduced drain permeability due to the inflow of finer particulates (i.e., clogging due to accumulating silt/clay) over time.

Figure 6 shows the current (yellow symbols) and former (red symbols) ground water monitoring well locations in the OLF area. The significant reduction in the number of monitoring wells limits the ability to assess the effects of land configuration changes and post-closure conditions on the ground water flow system.

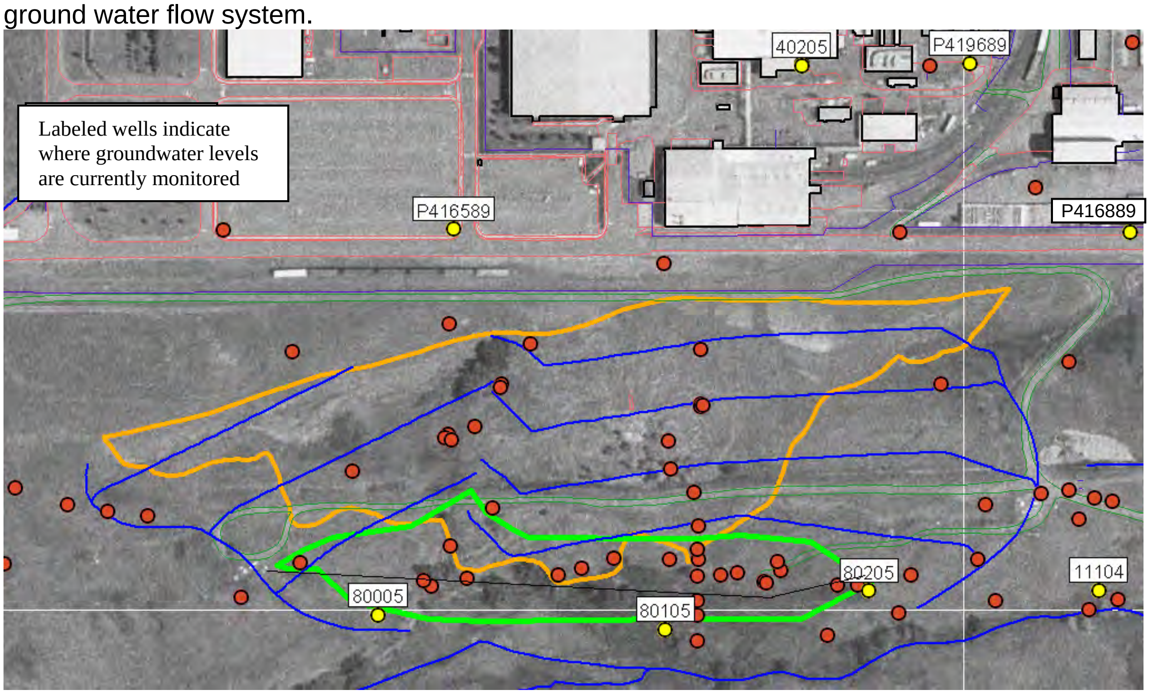


Figure 6. Current OLF area ground water monitoring well locations (yellow) and former locations (red). Ground water levels are only monitored in the current well locations. Photo base from pre-closure era.

Three wells, 80005, 80105, and 80205, are located below the clay buttress, and one well, P416589, is located upgradient (from P416589 south and downhill to Walnut Creek) in the former Building 440 area. Of these wells, only P416589 existed prior to closure. Post-closure ground water level data for these wells are shown on Figure 7 from approximately September 2005 to November 2006. Despite the expected seasonal change in ground water levels, pre-closure data for well P416589 suggest that no significant change in ground water elevation in the area (at least upgradient of the OLF) has occurred. In addition, data indicate that the responses in wells P416589 and 80105 (downgradient of the center of the buttress) are similar. Wells downgradient of the east and west ends of the buttress (80205 and 80005, respectively) show a similar although inverted response. This inversion at 80205 and 80005 may reflect the localized effects on ground water levels monitored by these wells from focused recharge from the nearby east and west perimeter channels.

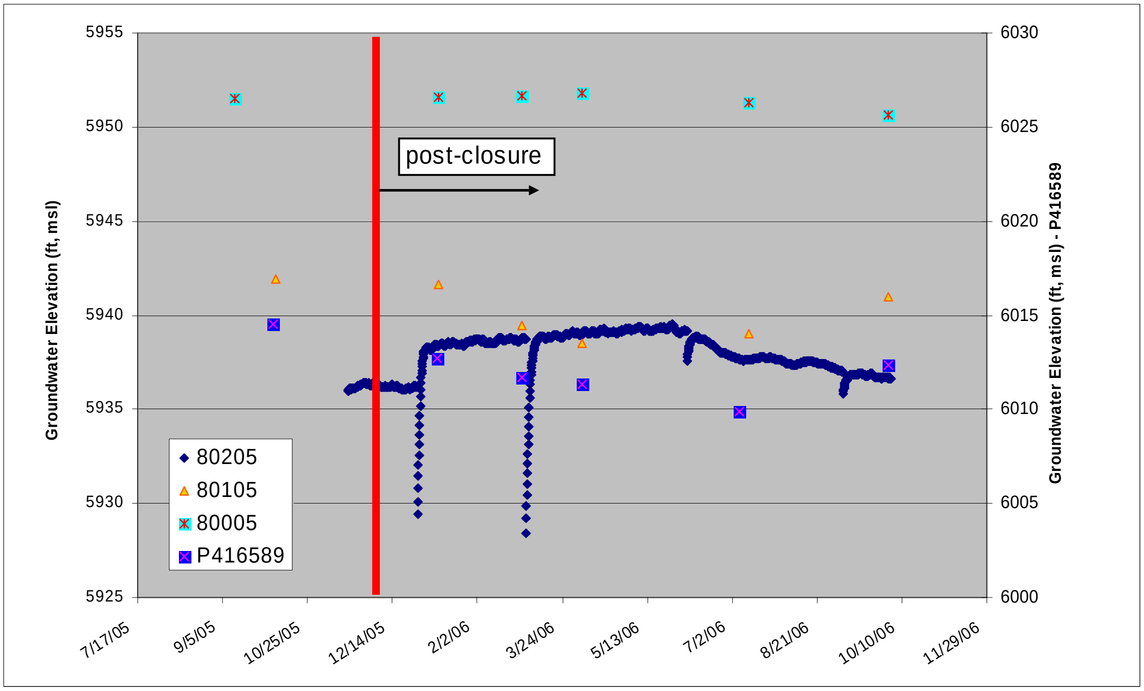


Figure 7. Post-closure ground water monitoring well water levels (ft amsl)

Surface water flow rates in the OLF diversion berms and perimeter channels are not measured. During May 2007, visual inspection of continuously flowing seeps (i.e., Seep #7 and the seep located just below the eastern end of the clay buttress, since named Seep #8) suggested a total combined ground water discharge of 10 to 20 gpm was occurring throughout the OLF area at that time.

2.0 Model Updates and Simulations

The last pre-closure OLF model simulations of planned post-closure conditions including the clay buttress, regraded topographic surface, and subsurface gravel drain (beneath the buttress) were performed in March 2005. These simulations did not show significant seepage, except for wet year conditions. General conclusions at the time were as follows:

- Seeps may occur in areas where weathered bedrock is shallow, depending on climatic conditions.

- Seeps might occur upgradient of the clay buttress if the gravel drain were to fail, either by lower-than-expected permeability of the underlying valley fill alluvial material, or reduced permeability caused by inflow of fine particulates.

The current post-closure information indicate three changes to the previous modeling that could be considered for updates:

1. New surface topography and surface drainage system;
2. Approximately 20 percent vegetation cover instead of fully established vegetation; and
3. Post-closure climate conditions.

Two preliminary simulations were conducted to evaluate the post-closure conditions. In the first simulation only the surface topography was updated, while in the second the surface topography and vegetation coverage were updated. The hydrologic response in both simulations was driven using the 1999-2000 climate year data because these data have been carefully assessed and synchronized in time (i.e., precipitation, temperature, and potential evapotranspiration [PET]). In addition, initially the time required to develop a new post-closure dataset was considered significant.

Initial simulations with just the new surface topography modification showed that most observed seep locations were well simulated (Figure 8). These seeps mainly occur where the thickness of unconsolidated material overlying the weathered bedrock surface is relatively shallow. This generally occurs where the surface topography was modified, or lowered to accommodate the surface drainage features. This is most pronounced along the southern ends of the side channels, which were originally not included in the previous OLF closure configuration (March 2005 version).

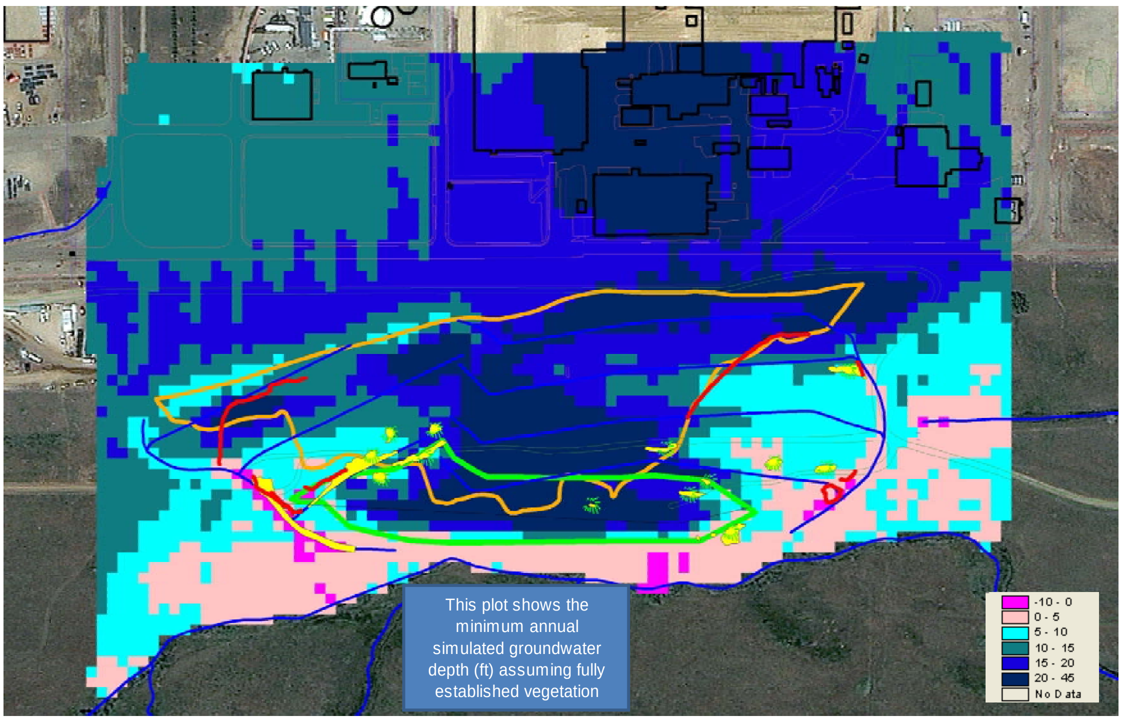


Figure 8. Minimum annual simulated ground water depth (feet) for updated model with only topographic modification and using 1999-2000 climate dataset. Observed seeps are shown in yellow, simulated seep areas are pink. Other features are as defined on previous figures. Photo base is from pre-closure era.

Results from the second simulation, which added vegetation updates, showed significant seep development, largely in areas where weathered bedrock is shallow, or over the footprint of the clay buttress as shown on Figure 9. Initial simulations also indicated that surface discharge at Seep #7 could not be reproduced. Because of the significant and continuous amount of discharge at this location compared to other seeps, the following available data were carefully reviewed for this area:

- 1937 aerial photograph;
- 1951 aerial photograph;
- Detailed borehole logs in the area (Figure 10); and
- Former mapped Arapahoe Sandstone distribution (Figure 2).

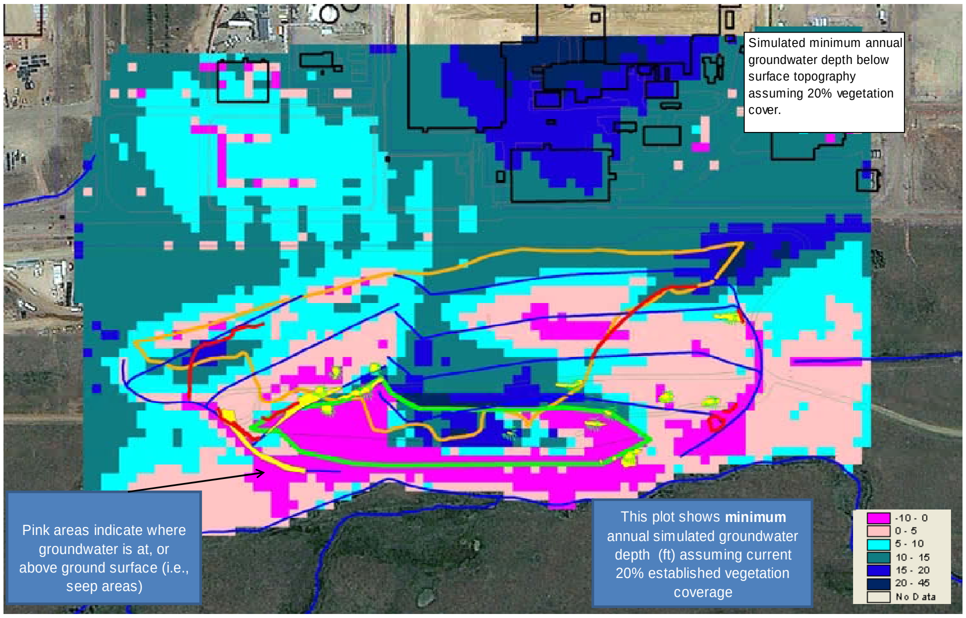


Figure 9. Minimum annual simulated ground water depth for model with topographic modification, 20% vegetation coverage, and using 1999-2000 climate dataset. Observed seeps are shown in yellow, simulated seep areas in pink. Other features as defined on previous figures. Much of the clay buttress shows saturation at the surface due to its flat topography and ponding of precipitation above clay material specified in the model at the surface. Photo base from pre-closure era.

Results of this review suggest that a sandstone body (informally referenced in historical site geologic reports as the Arapahoe Sandstone #1) immediately subcrops the unconsolidated material just north and west of Seep #7, as shown on Figure 10a. As illustrated on Figure 10b, this sandstone body increases in depth toward the east. The shallow or exposed sandstone along the former topographic face of the slope before Site development (visible on 1937 and 1951 aerial photographs) probably caused the former seep flow in this area. Reconfiguration of the OLF surface topography during closure likely caused the former seep to discharge at Seep #7.

The upgradient northern and western extent and configuration of the sandstone body are uncertain. However, it is likely connected to the larger generally southwest-northeast trending Arapahoe Sandstone body 200 to 300 feet northwest of Seep #7 (Figure 2). This Arapahoe Sandstone body is based on former mapping (EG&G, 1995) and extends generally northeast more than 4,000 feet. This body was included in the former OLF model, but did not extend to the Seep #7 area. Evaluation of available detailed borehole logs in the area suggests it probably does extend to the Seep #7 area. Figure 11 shows the distribution of the modified sandstone body subcropping the unconsolidated material, and its configuration and likely intersection with the previously mapped Arapahoe Sandstone (#1) body to the northwest.

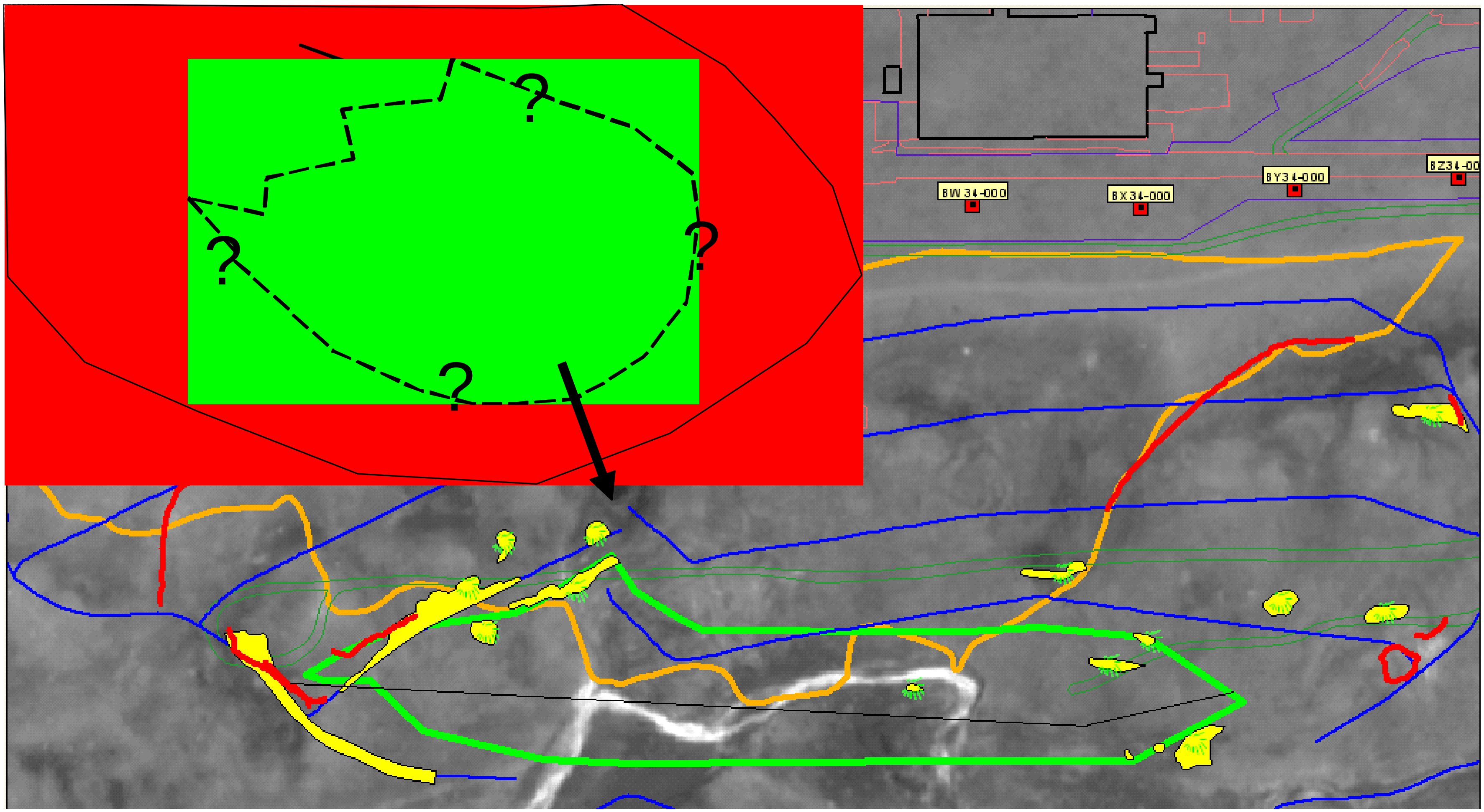


Figure 10a. Approximate location of sandstone (green) subcropping unconsolidated material, and trace of the lower extent of the sandstone (red) embedded in claystone/siltstone (below the contact between bedrock and unconsolidated material). A 1937 aerial map is shown. The sandstone plunges toward the east. This sandstone may be the source of the Seep #7 discharge.

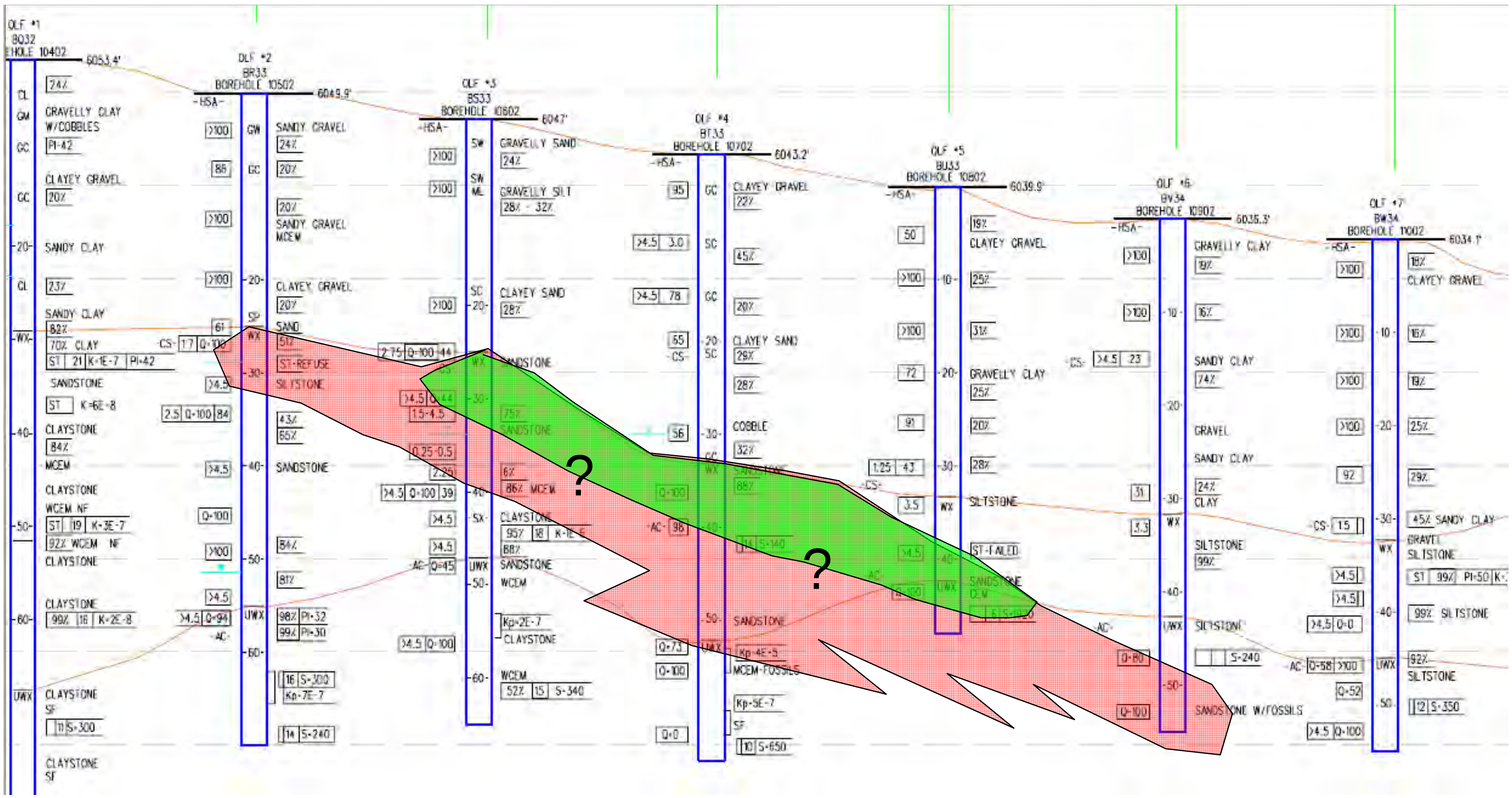


Figure 10b. West-east cross-section through boreholes just north of the OLF waste area and along the top of the slope. Borehole locations (blue), geologic data (text), and upper and lower contacts for the weathered bedrock (orange) are shown. This plot shows the approximate location and configuration of the continuous sandstone body referenced in Figure 10a.

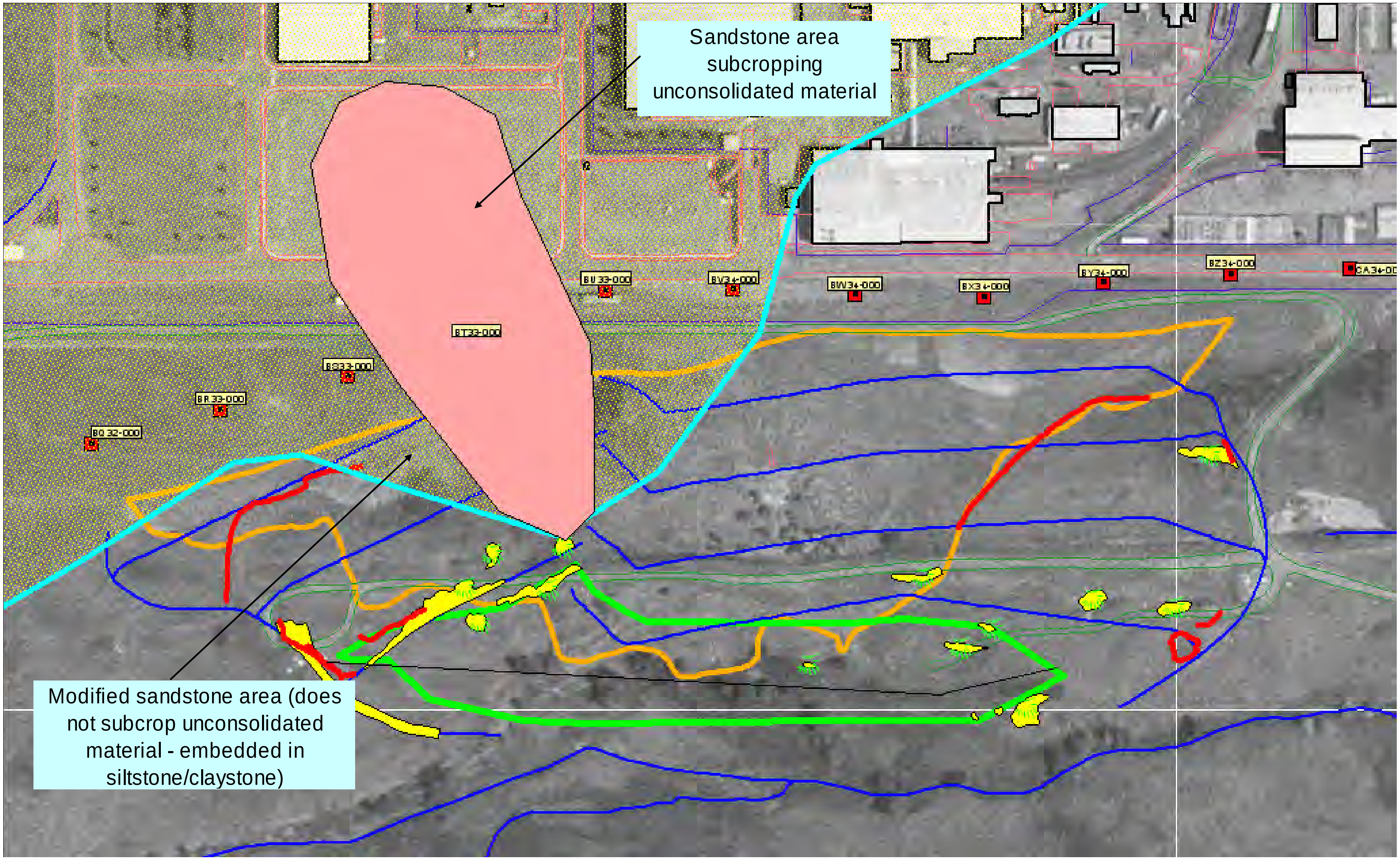


Figure 11. Extent of subcropping sandstone body at the OLF (pink) and its configuration and intersection with the former Arapahoe Sandstone #1 body to the northwest (northwest of light blue line). Compare with Figure 2, which shows previously mapped estimate of sandstone distribution. Photo background is from pre-closure era.

To generate the Seep #7 discharge area and flow rates requires that a pathway from the weathered bedrock to the surface topography exists through the unconsolidated and waste materials. Therefore, another modification made to the model, in addition to the extension of the higher-permeability sandstone body to the Seep #7 location, was to add a near-vertical permeable conduit to the surface to allow the former seep area to drain to the surface to reproduce observed surface discharge. Such a conduit could have developed during cut-and-fill operations associated with the OLF cover emplacement, although this area is relatively thick. It is more likely that the waste material in the OLF offers preferential pathways not typical of the natural Rocky Flats Alluvium (used as the cover material and assumed in former Site-Wide Water Balance modeling to have more uniform hydraulic properties).

Initial, localized simulations with the new sandstone body configuration suggested that the former hydraulic conductivity values (7.88×10^{-6} meter per second [m/s]) were too low to generate the observed surface discharge rates at Seep #7. As a result, these values were increased to between 1.0×10^{-5} and 1.0×10^{-6} m/s. The higher values were assigned to sandstone in model layer 3 (layers 1 and 2 are unconsolidated, and 3 and 4 are bedrock) which immediately subcrops the unconsolidated material. These are likely to be more weathered than the lower (1.0×10^{-6} m/s) sandstone that connects with the larger southwest-northeast trending Arapahoe Sandstone body to the northwest.

Climate Data Update (2002 to 2007)

High-quality, continuous post-closure climate data were obtained from the nearby (approximately 2 miles northwest of the IA) National Renewable Energy Laboratory (NREL) National Wind Technology Center (NWTC) M2 Tower station located at the western edge of the NWTC Site, approximately 7 miles west of Broomfield and 5 miles south of Boulder along Highway 93. The tower is 82 meters high and located at 39° 54' 38.34" N and 105° 14' 5.28" W (datum WGS84), with its base at an elevation of 6,085 feet (1,855 meters) above mean sea level (msl). These data were available online at http://www.nrel.gov/midc/nwtc_m2/.

Several datasets, measured every minute from October 1, 2001, to May 1, 2007, were downloaded from the NREL climate data weblink and include the following:

- Precipitation (heated gage provided snow water equivalent);
- Ambient air temperature (2-meter height);
- Dew point temperature;
- Wind speed (2-meter height);
- Relative humidity;
- Specific humidity;
- Total hemispheric shortwave irradiance measured with Precision Spectral Pyranometer (solar radiation); and
- Station atmospheric pressure.

The large volume of data required development of an MS Access database and several queries to format this information into model input using the MIKE SHE code format. The following model input was prepared:

- Fifteen-minute-interval precipitation data from October 1, 2002, to May 1, 2007. The downloaded data from October 1, 2001, to October 1, 2002, were not useable (anomalously high values) and were therefore omitted from the database;
- Hourly air temperature from October 1, 2002, to May 1, 2007; and
- Other hourly climate data including solar radiation, dew point temperature, wind speed, relative and specific humidity, and atmospheric pressure.

All of the hourly climate data and hourly precipitation sums using the 15-minute data were then compiled into an input dataset for use in the program REF-ET version 2.01.14 (Allen, 2000) to calculate hourly PET data for input into MIKE SHE. The hourly PET values calculated using this program represent those calculated using the full American Society of Civil Engineers Penman-Monteith equations for a reference grass crop. The MIKE SHE program uses this information, along with the vegetation Leaf Area Index (LAI), crop coefficients, root depths as a function of time, and several empirical parameters that control the effects of factors such as root densities with depth, plant interception, and the relative effects of soil evaporation compared to plant transpiration to calculate actual ET (AET). The new climate data represent high-quality information that can be expected to produce reasonably accurate input to the model.

Figure 12 shows long-term (several years) hourly temperature, precipitation, and PET data for the NREL wind site. For the purpose of modeling, it is significant that these data are highly correlated. For example, the PET and temperature often drop sharply during and shortly after each precipitation event. This can be important in capturing the infiltration and ground water recharge processes at the Site. This effect is more obvious on Figure 13, which shows only a month of data from August 1, 2005, to September 1, 2005.

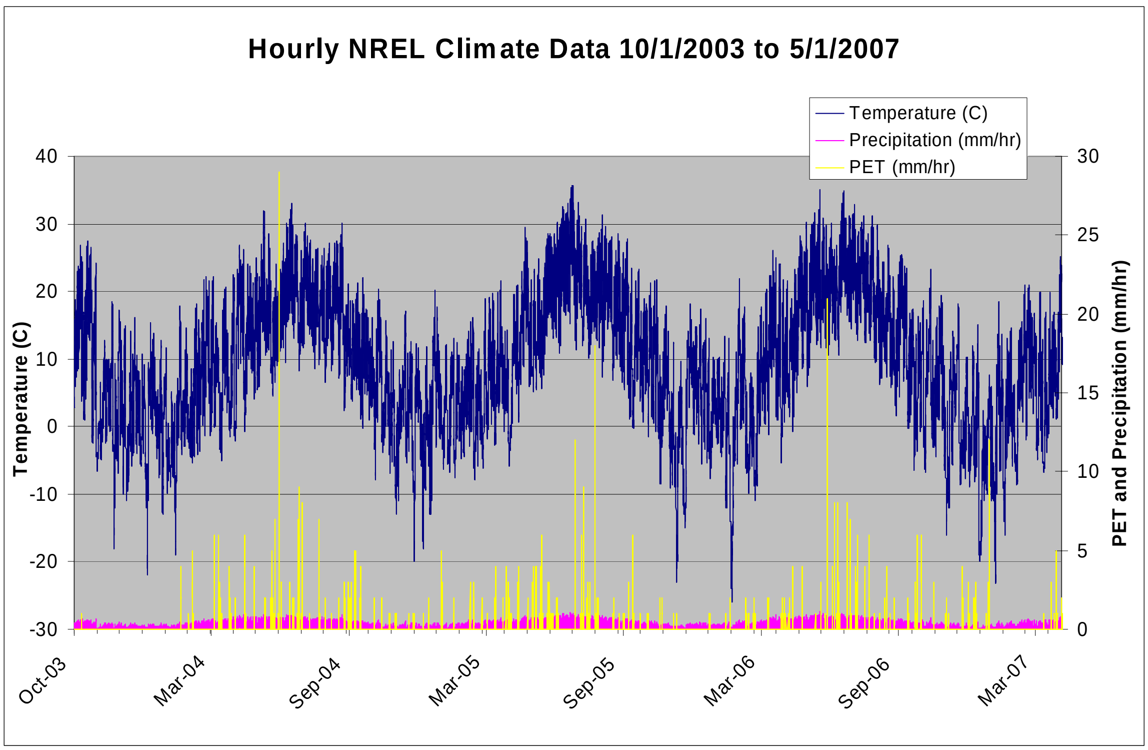


Figure 12. Hourly NREL temperature, precipitation, and PET data from October 1, 2003, to May 1, 2007

Field observations indicated that seeps within the OLF were more active due to the apparent higher precipitation from October 2006 to spring 2007. The NREL data were assessed to evaluate whether there were notable differences between the 2005/2006 and 2006/2007 time periods. Figures 14 and 15 present climate data for the two periods. It is clear that the fall 2006/winter 2007 time period exhibited notably higher precipitation compared to preceding years with subsequent snowmelt events that likely led to much greater recharge rates. This is also apparent in the decreased PET amounts over the same time period.

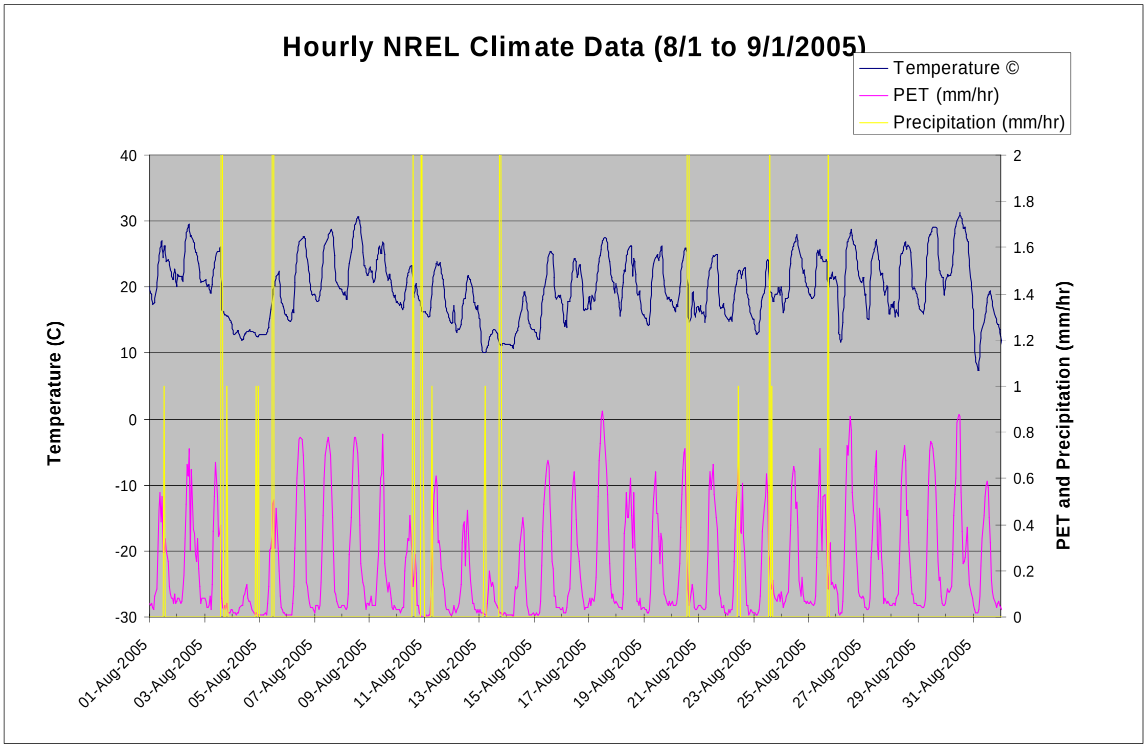


Figure 13. Hourly NREL climate data from August 1 to September 1, 2005

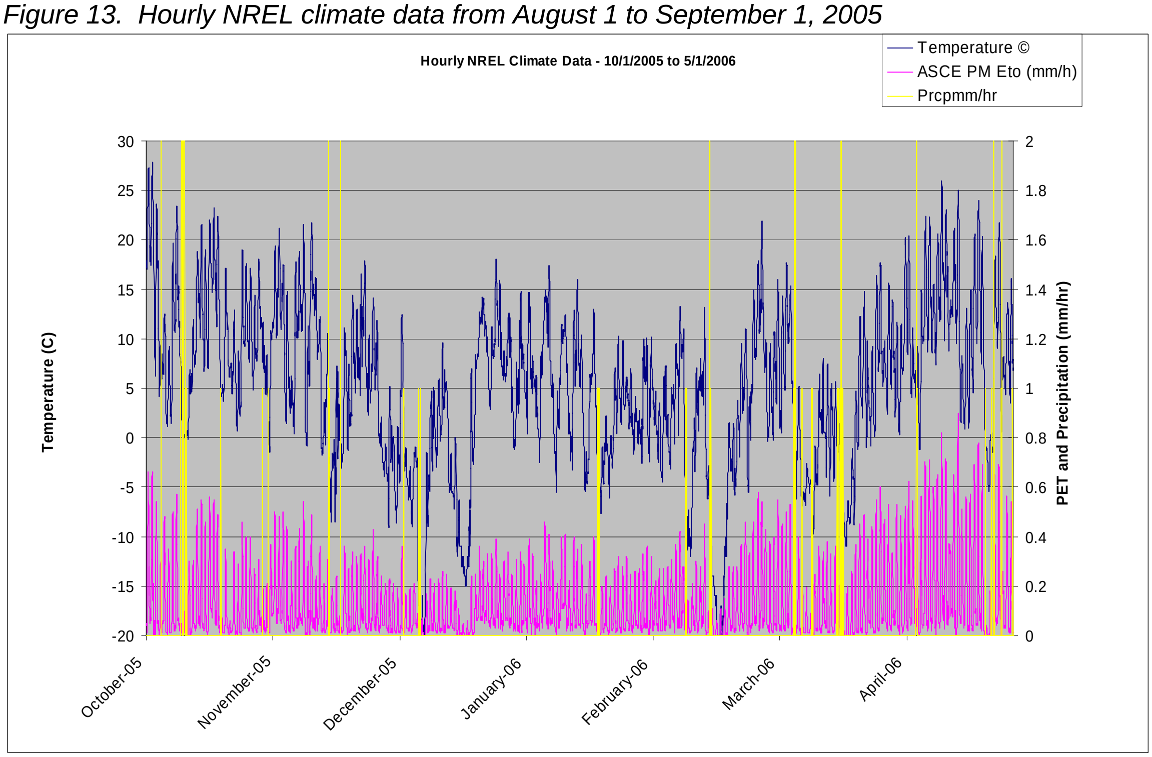


Figure 14. Fall 2005 to spring 2006 NREL climate data

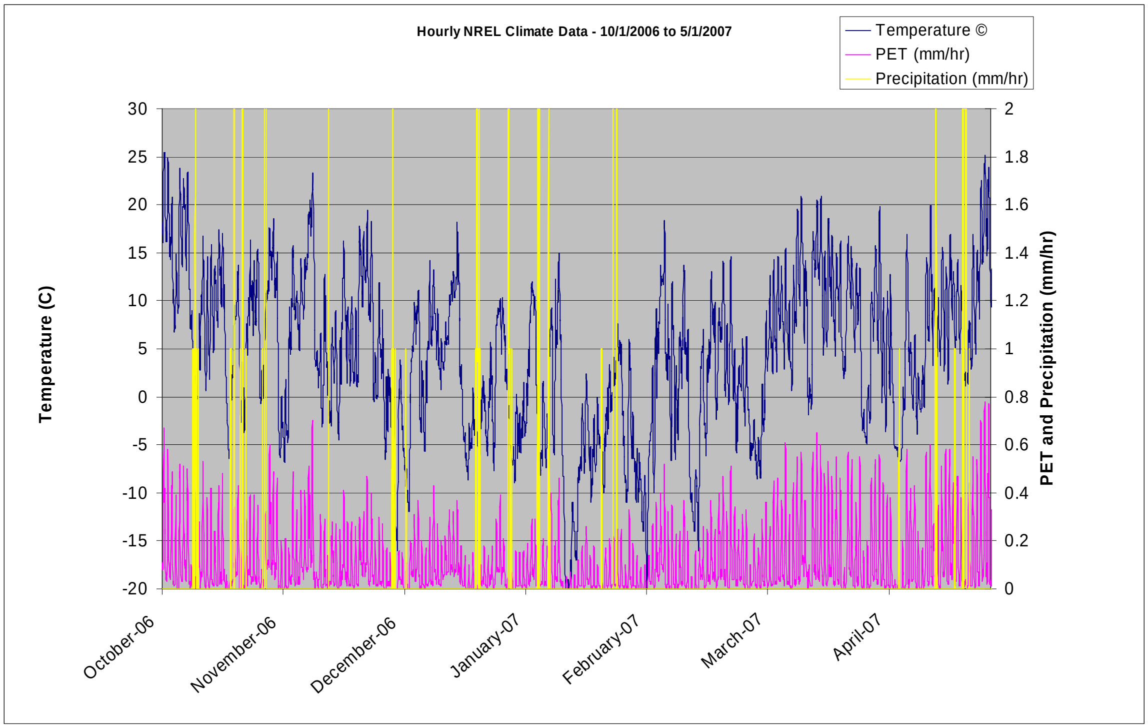


Figure 15. Fall 2006 to spring 2007 NREL climate data

Two longer-term simulations with the Arapahoe Sandstone revision described above were conducted using the updated 2003 to 2007 NREL climate dataset. This allows a more direct comparison between model-generated output and actual, more recent field observations of seep areas. One aspect that could not be accounted for in the model that might limit the comparability between simulated results and actual field observations is actual land configuration features modified during closure (as opposed to design configuration), and exactly how the features changed (i.e., building removal, pavement removal, drain removal, and OLF closure features). Another factor not accounted for is the quantity, timing, and locations of dust suppression water application during site closure activities. Finally, although geographically very close, NREL climate is not identical to that at the OLF.

Simulated ground water depths for both updated model runs are shown on Figures 16 and 17. The first model simulation (Figure 16), with the new sandstone modification and climate update, shows that ground water seepage occurs at Seep #7. The second model simulation (Figure 17) incorporates the constructed gravel drain to route ground water from the Seep #7 area into the gravel drain beneath the clay buttress. This simulation produced discharge at Seep #7 (less than 1 gpm) that is somewhat lower than observed (5 to 10 gpm), although the simulated areal discharge areas are similar. One reason for the lower simulated rates may be higher localized hydraulic conductivities than specified in the model. Another reason may be the configuration of the sandstone body (i.e., it may be much larger and therefore drain a much larger area than specified in the model).

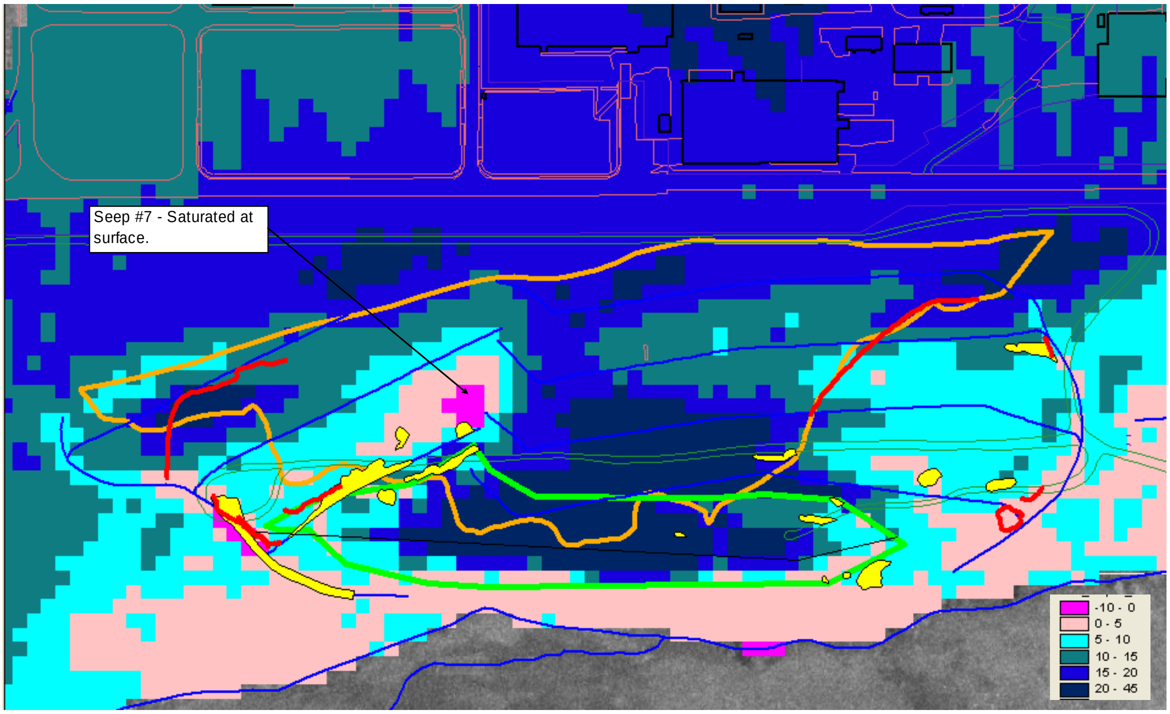


Figure 16. Simulated ground water depths (feet) for May 2007. Includes revision to sandstone and climate.

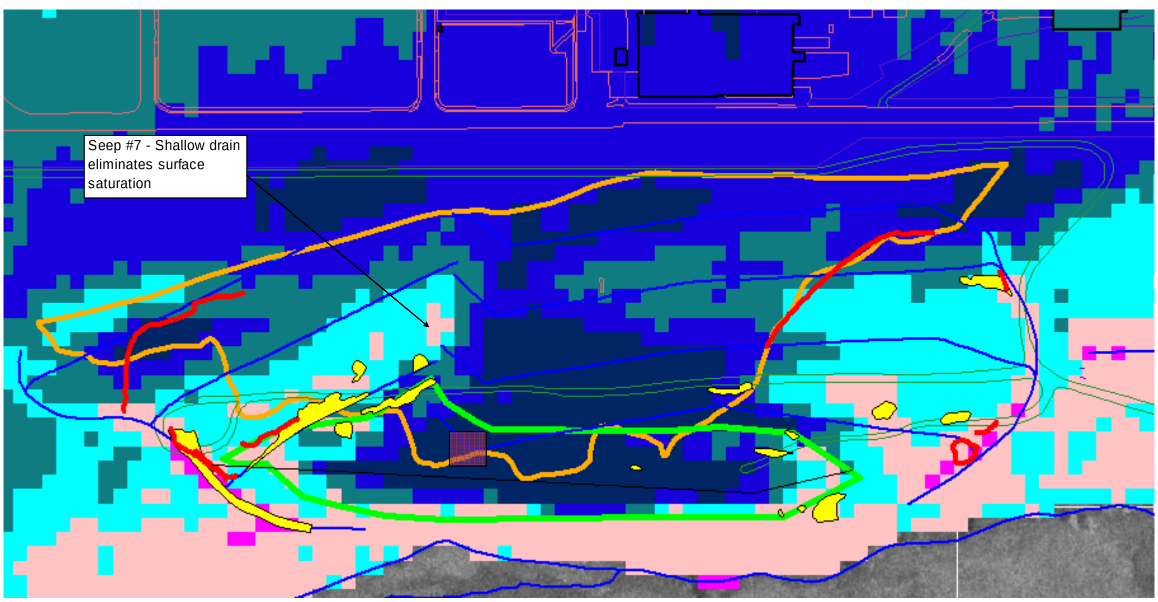


Figure 17. Simulated ground water depths (feet) for May 2007 with shallow drain (2 meters depth) at Seep #7 location. Includes revision to sandstone and climate.

3.0 Conclusions

Several conclusions based on evaluation of available post-closure data and updated model simulations are summarized as follows:

1) Many of the seeps identified in the OLF area occur in areas where weathered bedrock is relatively shallow (i.e., 0 to 10 feet). The updated model simulates approximate seep locations and discharge rates well.

2) Some seeps, such as Seep #7, are not related to shallow bedrock, but more likely associated with pre-existing seeps associated with subcropping sandstone bodies. One reason for the relatively continuous surface discharge in these areas may be due to the higher permeability of the sandstone compared to surrounding lower permeability bedrock. Surface discharge at Seep #7 likely makes its way to the surface through the landfill waste via a preferential pathway.

3) Simulated groundwater flow directions are similar between former post-closure simulations (March 2005) and the updated post-closure model described here. As a result, VOC pathways in groundwater are generally the same as indicated in previous modeling (Kaiser-Hill, 2004), though this previous fate and transport modeling did not consider discharge to the surface as seeps.

4) It is likely that the total seep discharge as of May 2007 is relatively high (i.e., estimated visually at 10 to 20 gpm total) for several reasons:

    a. More than twice the average precipitation from October 2006 through January 2007 fell mostly as snowfall and caused significant snowmelt, surface runoff, and ponding.

    b. Low vegetation coverage (approximately 20 percent of fully established) decreases the amount of ET loss and leads to increased ground water levels.

    c. Surface flow over the OLF is channelized; however, these channels together with very small-scale local depressions (or larger ones on the plateau to the northwest) can focus infiltration that leads to increased recharge to the shallow ground water flow system, which in turn increases the potential for surface discharge as seep flow.

    d. Significant topographic modifications along side channels have greatly reduced the depth to weathered bedrock, and in some instances have intercepted it. This forces nearby, localized discharge of ground water to the surface.

    e. The constructed gravel drain beneath the clay buttress may not drain upgradient ground water as efficiently as planned. This may increase the seepage that occurs at the surface just uphill and on the western buttress area.

5) Constructing a shallow subsurface drain over the extent of the Seep #7 area, which routes flow past the buttress either directly over it, or via a pipe to the side channels could be effective at:

    a. Reducing surface discharge in this location and, probably more importantly,

    b. Reducing direct surface runoff from Seep #7, along the berm and into the side channel, which is already experiencing slumping and seepage due to the shallow weathered bedrock depths resulting from the steep cuts.

6) To assess its performance, an effort should be made to obtain continuously monitored ground water pressures (i.e., Troll data) within the gravel drain beneath the clay buttress, particularly downgradient of Seep #7. This information could be useful in assessing how efficiently the gravel drain is routing upgradient ground water beneath the buttress and into the Woman Creek valley fill alluvium to the south.

4.0 References

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